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PROCEEDINGS OF THE ENVIRONMENTAL QUALITY SENSOR WORKSHOP HELD AT LAS VEGAS, NEVADA ON NOVEMBER 30-DECEMBER 2, 1971

Environmental Protection Agency
Washington, D.C.

10 January 1972

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PROCEEDINGS

ENVIRONMENTAL QUALITY SENSOR WORKSHOP

November 30 - December 2, 1971
Western Environmental Research Laboratory
Las Vegas, Nevada

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FOREWORD

The problems arising from man's interaction with the environment are real and, in some instances, serious. Basic to the study of these problems (how they arose, how they can be solved, how they can be prevented) is the province of environmental monitoring and analysis. An important aid in these investigations is the province of remote and in situ sensors utilized in environmental monitoring.

In order to bring together those individuals within the Environmental Protection Agency (EPA) that are directly concerned with the monitoring and analysis activities, an Environmental Quality Sensor Workshop was held at the Western Environmental Research Laboratory, Las Vegas, Nevada, November 30 through December 2, 1971. The Workshop was convened in order to acquaint those in EPA responsible for monitoring environmental quality with the latest techniques for sensing environmental pollutants. In addition, there was an attempt to understand the requirements for sensor systems in each region and to discuss possible applications of the appropriate sensor technology. In order to achieve the desired communications and response from the participants, the attendance was limited to EPA personnel from Headquarters, the Regions, Centers, and Laboratory and those Federal Agencies with interests in environmental monitoring. A roster of attendance is included in this report.

The Workshop consisted of a number of invited tutorial papers which included all pollution categories and panel discussions devoted to sensor techniques, sensor platforms, data management and sensor priorities. Complete texts of the tutorial papers and summaries of the panel discussions are included and constitutes the major portion of this document.

Following the Workshop a series of recommendations and action items were prepared by the Monitoring Techniques Division based on discussions and suggestions resulting from the Workshop. All of the recommendations support the basic theme of the Workshop: To determine the applicability of remote and automated in situ sensing within the Environmental Protection Agency.

The program and agenda were prepared by a Steering Committee consisting of sensor experts within the agency. These include:

- J. Koutsandreas - Steering Committee Chairman, ORM
- S. Verner - Vice Chairman, ORM
- R. Holmes - Executive Secretary, ORM
- D. Ballinger - NERC, Cincinnati, Ohio
- L. Dunn - WERL, Las Vegas, Nevada
- A. Ellison - NERC, Raleigh, North Carolina
- M. Felsher - Office of Enforcement
- D. Krawczyk - NERC, Corvallis, Oregon
- L. Swaby - ORM
- C. Weber - NERC, Cincinnati, Ohio

The proceedings are arranged in two basic divisions: Part I includes the preliminary report of the Workshop, Recommendations and Actions and the Agenda; Part II presents the general proceedings; and the Appendices include a WERL news release, a list of attendees and a glossary of abbreviated terms.

10 January 1972

Donald C Holmes

Donald C. Holmes
Director
Monitoring Techniques Division

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PART I

A. Preliminary Report

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PART I

A. Preliminary Report

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

December 7, 1971

MEMORANDUM

TO: Assistant Administrator for Research and Monitoring

THROUGH: Deputy Assistant Administrator for Monitoring

SUBJECT: Preliminary Report of the Environmental Quality Sensors Workshop

The first annual environmental quality sensors workshop was convened for the purpose of acquainting those in the Agency responsible for monitoring environmental quality with some of the latest state-of-the art techniques for sensing pollutants. Mr. Willis B. Foster expressed the foregoing purpose and established the workshop theme by calling for a reliable, efficient and timely monitoring program based on the most advanced concepts in sensor technology. Such a program, implemented on an EPA-wide basis for the total environment, will enable the Agency to meet the challenge of creating and maintaining a healthful environment. This is in accord with the primary mission of EPA to set environmental pollution standards, to regulate, and to enforce.

The workshop was organized so that the participants were given presentations in terms of EPA's responsibility for the total environment. Every opportunity to mute organizational biases was taken, and, although each tutorial speaker addressed a particular area, the workshop is believed to have been reasonably successful in inducing the participants to perform the necessary integration so that sensor system requirements were considered from a total environmental point of view. Participation of some 55 individuals included representatives from each NERC, WERL, nine regional offices (Region III was not represented so we plan to take a summary workshop to them), and ten other federal agencies.

Dr. Delbert Barth established an extremely important tone for the meeting in the initial tutorial paper on monitoring needs and systems to meet those needs for air pollution. He also emphasized in his closing remarks, that to fulfill the EPA purposes set by President Nixon when he created the Agency, the essential requirement is to develop a coordinated environmental monitoring system. A continuation of his closing remarks follows:

"...We are never going to get there until we find out where we are now. We have to determine our starting point. That means we have to get to know one another, the people who have been in air and know the air program have to find out about the water program and the water people have to find out about the air and all the other things, solid wastes, radiation, pesticides. A meeting like this goes a long way towards getting at least a start in that direction. I hope that starts that have been made here will be built on in the future, and in fact we will be able to develop a coordinated and integrated monitoring program. In so far as the NERC at the Research Triangle Park is concerned, I assure all of you in the various Regions that we will do our very best to help you in any way that we can through the provision of technical advice, consultation, technical services, and in general to do our very best to help you in our areas of expertise. In my own judgement I think the biggest need we have in this program is the old problem of developing the environmental monitoring system into an integrated one. We can not continue to proliferate more and more measurements for more and more detailed pollutants at more and more stations throughout the entire U.S. We have got to do a better job at developing more efficient systems. To do this we need indices of total environmental pollution. We need to develop monitoring systems where we can get the data we need for air, water, solid waste, radiation, pesticides and noise in some kind of an efficient pattern, and not with a continued proliferation of more and more stations and more and more locations to sample for individual pollutants. That would be a never ending process which becomes extremely expensive. Certainly in a time when we do not have enough funds, it has to be one of the directions in which we must move. The second thing I think we need, and perhaps the most important, is better predictive models. The better our models are the fewer number of points we have to sample at in order to determine what the environmental quality is. So these are the two big things that I see that are needed in this entire area..."

Jack McBride closed for WERL as follows:

"...From reports given to me I was told that in several of the meetings the lack of funds or requirements for more funds came up. I would like to leave you with a slightly controversial note and say that maybe this is a blessing in disguise for all of us. Because in one way it makes us look to each other to see how we can get the help that Dr. Barth and Mr. Holmes were talking about. It makes us look to other agencies and within the organizational structure of EPA to see how we can get help. I think that once we get ourselves coordinated then we can take better advantage of the funds that are given us..."

Finally, the closing comments from John Hagan, speaking for Region IV, Carl Walter from Region VI and Robert Bowden from Region V seem fairly representative of the total regional viewpoint of this workshop, and follow verbatim.

"...I must admit I am going away much more optimistic than I was at the opening. The conference has somewhat changed in the way it has developed. It is not the same kind of a conference today that it was Tuesday morning. We started out with Regional people who are involved in day-to-day activities trying to get something accomplished at a work-a-day level. We started out also at the other end of the spectrum with people from headquarters and from the Office of Research and Monitoring who had technical capabilities which are beyond most of the understanding or capability in the Regions; and I think in the three days that we have been together we have begun to communicate with each other and come to understand each others problems. We are no longer talking about remote sensing. I think that as of this afternoon we have been talking about an environmental surveillance and monitoring program, not specifically a remote sensing program. I believe this is progress in the right direction. My central theme, which I've repeated often is that at the Regional level we are involved in implementing present technology, but present technology is much more sophisticated than most of us have implemented. I know about the great advances in satellite communications. That is the only place that I know that the EPA uses satellites. That is present technology and it should be implemented at the regional level. The use of sensors, the technology transfer from the point of the instrument development to the point of testing and field application I think should be given much more emphasis at the regional level. I think we have opened some lines of communication here to get that flow of information going and cooperation started. From that standpoint I think the Conference has been a great success. Personally, to me, it has been a great success in getting to know many of you individually that I haven't met before, and also finding out some of the things that are going to affect us in the regional surveillance operation. Water, traditionally, has had regional surveillance and monitoring programs. Almost all of the other programs represented here today and represented within EPA, have done their monitoring and surveillance at least in large regional east and west laboratory types of setting or on a national scale. If EPA is going to functionalize its organization at the regional level I think some of the centralized programs are going to have to be decentralized. On the other hand, if the monitoring program is ever going to amount to anything, other than the shotgun approaches of going out and bringing in anything that is standing still, we have to have some Headquarters' direction and establishment of priorities. In terms of trying to organize EPA into a functional organization the programs can learn from one another from past experience, and I hope that this forum has served to point that out. As I say, I came pessimistic and go back quite excited about the possibility of doing aerial scanning for preliminary investigation type of work. I go back anxious to implement a noise program for evaluating environmental impact for a proposed new airport in the Atlanta metropolitan area. I go back with high hopes that the Regions will develop the capability to respond to air pollution episodes, such as we had in Birmingham, and at the same time depend to a large extent on the capabilities that are being developed at the National Research Centers to back us up with the research and technology required.

Only one other thought should be expressed on EPA's relationship with other agencies. This is a very touchy situation because it is often decided on levels so far above me that I often times do not comprehend what they are trying to do. I feel that there is a great tendency to draw upon NASA or the Geological Survey, or NOAA or some other organization which has a capability that we should try to use. It is immediately obvious that there are going to be advantages, economic advantages as well as technical advantages, to cooperate. I think EPA has got to be very careful in this particular situation, that we maximize our cooperation without shirking our responsibility. In other words, we cannot give our responsibility, which was given to us by law, to another agency. It might mean not responding quite so fast to some of these things. It might mean transferring technology from NASA to EPA rather than us just going and hiring NASA to do the job for us. I feel very strongly about this and I feel that EPA has a mission to do. I don't think they should give that mission to anybody else, either contractually or through interagency agreements. I would like very much for some of the other regional people that are still with us to say something, I know that Carl Walter and Robert Bowden are never at a loss for words and perhaps they could add something to this regional viewpoint..."

Robert Bowden, Region V:

"...I would like to make one point, and that is to implore a little better coordination with what is going on in other federal agencies. I mean I've met people here in these three days and found out things that I didn't even know were going on. It is impossible to find this out at the Regional level, I think, and what I believe is that we do have people in our Office of Research and Monitoring in Headquarters who are making contact with these people and trying to integrate a program. There should be some better communication down to the regional level to let us know what is being developed and how we can use either their techniques or their resources and to help us implement another program. I think it has been pointed out quite emphatically that we are short of manpower, we are short of resources and therefore we are often forced to go back to the hard way of doing it, the manual way of doing it, rather than drawing upon advanced technology..."

Carl Walter, Region VI:

"...I would like to make only two comments. In our Region we have only four states, but we have two states that are now actively interested in remote sensing and one of them is pretty far down the line. In their Office of Geological Survey, that's Iowa's Geological Survey, they acquired some multi-spectral photographic equipment plus some image enhancement equipment. They have this capability, they have hired some people that are knowledgeable in remote sensing and they have organized in the state to the point where the Geological Survey in Iowa represents 22 other state agencies. It is going to be a fine focal point for the usage of remote sensing in the state. Now there may be other states that are in this same situation, where they are actually aware of these techniques. I suggest this is an area where we can have some very fruitful cooperation. The second thing that I would like to say is that when we go out to collect data that we must concern ourselves only with what data is actually needed, and will be analyzed and used..."

A few other points need to be made concerning the Workshop. It appeared that the participants did recognize the potential value of long-term research, even though emphasis was placed primarily on current technology. Even here, however, the regions appear hampered because they don't always know what is better or what a new and advanced monitoring system will do for them. They're constrained because of limitations on people and funds from being as innovative as they are capable.

Wide knowledge of inter- and intragency existing capabilities, and procedures for drawing upon them, are woefully weak. It is an area needing early attention and support as part of our monitoring program aimed at the total environment. The individuals are believed receptive to this.

From the Headquarters' view, if we expect to derive the full potential from application of remote or in situ sensors on suitable platforms, we will have to exert a strong push. At the same time requisite ground truth and data management and interpretation need complementary effort, as does standardization of methods and equipment.

As Dr. Barth noted, we need more predictive modelling to reduce the number of sampling points. We also need emphasis on sampling techniques and monitoring site location, since deficiencies in these areas often are attributed to analytical measurement shortcomings.

A follow-on industrial conference needs to be planned so that we can translate some of the sensor/platform requirements to industry at large. This would allow further elucidation of what industry now has on the shelf. A useful result of such a conference would be a comprehensive compendium of sensors, appropriate platforms, and details of how to use, what limitations to expect, costs, and things of this nature. As a first step, the survey, "Instruments for Environmental Monitoring," being completed by the Lawrence Berkeley Laboratory, under National Science Foundation (Research Applied to National Needs (RANN)) auspices, should be available in January 1972 for distribution.

As part of the foregoing, and before planning another workshop, we need to plan and develop a training course for the regional Surveillance and Analysis members. Preferably, it should be taken to them as part of our responsibilities for coordination and planning for Agency monitoring.

In considering EPA interaction with other Federal agencies, many opportunities are immediately brought to mind. The National Bureau of Standards efforts in analytical and reference methods is perhaps paramount, and we should place a significant amount of additional support in this effort with them.

The National Science Foundation, through its program of RANN has a sizable budget and an interest in supporting appropriate work based on EPA recommendations. OR&M is the focal point for this program, and a memorandum of understanding is being drafted with NSF to delineate operating procedures.

The National Photographic Interpretation Center is a unique organization, and one with which EPA should be involved in developing certain sensor data interpretation techniques and a training effort for selected regional personnel.

The Office of Civil Defense made a brief presentation which highlighted a number of capabilities which EPA may wish to utilize. Among them are its instrument repair and calibration activity existing in each state; the Civil Air Patrol fleet of some 6000 aircraft, 18,000 pilots, and 30,000 cadets; the annual survey of shelters which might be capable of adding sociological sampling of interest to air and noise; the rather extensive training program; and the extensive hard-line communication system.

My closing note concerns the rather notable advances we seem to have made in this workshop toward implementing a functional approach to the EPA monitoring effort. In this one regard, I believe the workshop more than paid for the time, effort, and funds involved.

Donald C Holmes
Donald C. Holmes
Director
Monitoring Techniques Division

PART I

B. Recommendations and Actions

RECOMMENDATIONS AND ACTIONS

The following are recommendations and proposed actions which were generated by the Sensor Workshop. Some are a direct result of the panel sessions, while others were suggested by the Steering Committee members and the General Chairman. Generally, these recommendations are based upon the following major premise: There is an immediate requirement for utilization of remote and automated in situ sensors for monitoring environmental quality.

1. Recommendation: Determine the monitoring plan and programs for each Region.

   Action: The Monitoring Techniques Division will assist the Surveillance and Analysis Divisions in developing specific monitoring plans for each Region. These plans will at least consider the following: Resources necessary; sensors and platforms to be utilized; priority assignments and an inventory of problem areas in each Region.

2. Recommendation: Establish a comprehensive sensor data management facility with the capability of supporting monitoring activities in the Regions.

   Action: The Monitoring Techniques Division in coordination with the Monitoring Analysis Division will undertake appropriate action to identify WERL as the EPA location for the acquisition and processing of remote sensor data.

3. Recommendation: Establish standards for instruments which acquire data by remote and automated in situ sensors so as to ensure quality and compatibility with existing EPA data systems.

   Action: The Standard Methods Branch in conjunction with the Sensors Branch of the Monitoring Techniques Division will help identify and prepare requirements for remote and automated in situ sensor data acquisition, transmittal and processing techniques.

4. Recommendation: Establish a standardized storage and retrieval system capable of accepting data from all elements of EPA and format compatible with systems currently in use at other Federal Agencies, e.g. NASA, NOAA and USGS.

   Action: The Monitoring Analysis Division will examine the existing storage and retrieval systems and will inventory their capabilities and limitations. The review will include: the sensor data needs of EPA; an identification of existing data storage and retrieval facilities, a recommendation for the design of approaches which would utilize existing environmental systems and data to meet the Nation's environmental needs.

5. Recommendation: Inform the Regions, Laboratories, and Headquarters Offices of sensor activities in other Federal Agencies which relate to environmental monitoring.

   Action: The Monitoring Techniques Division, Sensors Branch, will periodically furnish information on the types of sensors being used and the amounts of sensor data available.

6. Recommendation: Prepare a compendium of information on the sensors which were discussed during the Workshop.

   Action: The Sensors and Standard Methods Branches of the Monitoring Techniques Division will compile and distribute the compendium.

7. Recommendation: Inform industry representatives of the appropriate aspects of the Sensor Workshop.

   Action: The Monitoring Techniques Division, Sensors Branch, will contact GPO to determine the requirements for reprinting and selling the proceedings of the Sensor Workshop to industry. The Advanced Techniques Branch will plan and prepare a follow-up briefing for representatives of interested industrial firms.

8. Recommendation: Identify the ERTS experiment proposals which are of particular interest to the Regions.

   Action: The Monitoring Techniques Division, Sensors Branch, will prepare a recommended program of ERTS experiments which would involve EPA scientists and engineers from each Region.

9. Recommendation: Design a standard format for EPA's remote platform monitoring mission requirements.

   Action: The Monitoring Techniques Division, Standard Methods Branch, in cooperation with WERL will establish a uniform mission request form and disseminate it to the users.

10. Recommendation: Prepare an informational newsletter which would focus upon the latest developments in such areas as environmental sensor technology, new monitoring techniques, standard methods and recent regional monitoring activities.

    Action: The Monitoring Techniques Division will investigate the requirements for publishing a quarterly newsletter and for compiling a yearly digest of significant articles on environmental monitoring.

11. Recommendation: Conduct a one week familiarization course on environmental sensors for the benefit of the Regional Surveillance and Analysis and Enforcement Divisions during CY-1972.

    Action: The Monitoring Techniques Division, Sensors Branch, in conjunction with WERL and the EPA Training Division will develop a one week Sensor Familiarization Course on remote and automated in situ sensors which will examine their capabilities, limitations and implementation potential.

12. Recommendation: Prepare a briefing of the Sensor Workshop for appropriate individuals in Region III.

Action: The Monitoring Techniques Division, Sensors Branch, supported by the necessary elements of EPA will prepare and present the recommended briefing.

13. Recommendation: Conduct an annual sensor workshop, similar to the first, but with greater emphasis on regional planning for sensor utilization; and include a review of regional monitoring activities and priorities.

Action: The Monitoring Techniques Division, Sensors Branch, will plan a sensor workshop in FY-1972.

PART I

C. Agenda

AGENDA

ENVIRONMENTAL QUALITY SENSOR WORKSHOP
WESTERN ENVIRONMENTAL RESEARCH LABORATORY
LAS VEGAS, NEVADA
NOVEMBER 30 - DECEMBER 2, 1971

November 30

8:30 - 12:00 PM OPENING PLENARY SESSION

Welcome - Dr. Melvin Carter, Director
Western Environmental Research Lab

Workshop Theme - Mr. Willis B. Foster
Deputy Assistant Administrator
for Monitoring

Remarks by Workshop Chairman - Mr. Donald C. Holmes
Director
Monitoring Techniques Division

ENVIRONMENTAL TUTORIAL SESSION

9:00 - 10:00 "Monitoring Needs for Air Pollution and Systems Required to Meet Those Needs"
Dr. Delbert S. Barth, Director
National Environmental Research Center
Research Triangle Park

Dr. S. David Shearer, Director
Division of Atmospheric Surveillance
National Environmental Research Center
Research Triangle Park

10:00 - 11:00 "Optical Methods for Detection of Water Pollution"
Dr. S. Q. Duntley
Director, Visibility Lab
Scripps Oceanographic Institute

11:00 - 12:00 "Remote Sensing of Environmental Quality in Relation to Land Management"
Dr. L. W. Bowden
Chairman, Department of Geography
University of California, Riverside

November 30 (continued)

12:30 - 2:00 PM TOUR OF EPA AIRCRAFT

2:00 - 5:30 PM Sensor Monitoring Techniques Workshop

Plenary Session - Mr. John Koutsandreas

National Science Foundation "RANN" Program, Dr. Paul Craig

"Analytical Problems in Air Pollution Control"
Dr. P. Altshuller, EPA

"State-of-the-Art in Noise Monitoring"
Mrs. E. Cuadra, EPA

4:00 - 5:30 Concurrent Panels

Panel A - Contact Sensor Techniques Panel
Chairman, D. Krawczyk, EPA

Panel B - Non-Contact Sensor Techniques Panel
Chairman, S. Verner, EPA

December 1

8:30 - 12:00 PM Sensor Platforms Workshop

Plenary Session - Mr. John Koutsandreas, EPA

"Approaches to Water Quality Monitoring"
Mr. William Sayers, EPA

"In Situ and Remote Sensing for Solid Wastes"
Mr. Harry Stierli, EPA

10:00 - 12:00 Concurrent Panels

Panel A - Marine and Terrestrial Panel
Chairman, Dr. M. Felsher, EPA

Panel B - Aircraft and Spacecraft Panel
Chairman, Mr. L. Dunn, EPA

December 1 (continued)

1:30 - 5:30 PM	Sensor Data Management Workshop
	Plenary Session - Mr. John Koutsandreas
	"Radiation Sensing—Current Review" Mr. V. Andrews, EPA
	"Sensor Data Management for Monitoring Pesticides and Related Compounds" Dr. G. Wiersma, EPA Dr. H. Tai, EPA
3:00 - 5:30	Concurrent Panels
	Panel A - Current Data Systems Panel Chairman, J. Reagan, EPA
	Panel B - Future Data Systems Panel Chairman, Mr. E. Grenning, EPA

December 2

8:00 - 10:00 AM	Survey of Remote Sensor Instrumentation D. Bundy, EPA - Multiband Cameras J. Sherman, NRL - Multispectral Scanners A. LeFohn, EPA - Spectrometry M. Felsher, EPA - Laser Bathymeter
10:00 - 11:00	Summaries from Workshops I, II, & III
	Sensor Priorities Workshop
	Concurrent Panels
	Panel A - Short Term Panel (1-5 yrs) Chairman, Dr. C. Weber, EPA
	Panel B - Long Term Panel (5-15 yrs) Chairman, Dr. A. Ellison, EPA
1:30 - 2:00 PM	Summaries from Workshop IV
2:00 - 3:00	Closing Plenary Session Mr. Donald C. Holmes, EPA
3:00 - 3:30	Use of OCD for Environmental Monitoring R. Sandwina, OCD
3:30 - 4:30	TOUR OF WERL FACILITIES

PART II

A. Workshop Theme

B. Opening Remarks

C. Tutorial Papers (3)

D. Program Papers (6)

E. Workshop Discussion Topics

F. Workshop Panel Summaries

G. Closing Remarks

H. Appendices

    News Release

    Roster of Participants

    Glossary of Terms

PART II

A. Workshop Theme

WORKSHOP THEME

Willis B. Foster
Deputy Assistant Administrator for Monitoring
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C.

I would like to add my words of welcome to those of Dr. Mel Carter in wishing you a fruitful and productive Workshop.

We have organized this meeting to bring together those responsible for monitoring environmental quality to engage in a free exchange of ideas and to learn firsthand about the monitoring activities and requirement of the ten EPA regions. In this way we hope to gain a better understanding of how sensing technology, both remote and in situ, may be directed to answering the needs of the regions, states and municipalities.

For those of us in EPA responsible for monitoring the environment, a further benefit I see arising from the Workshops to follow over the next three days and from the tutorial papers we will hear this morning is an appreciation and awareness of the latest advances in the state-of-the-art sensors and monitoring technology.

I needn't remind this audience that EPA is basically a regulatory agency whose primary function is enforcement of environmental quality standards established by statute. Central to this endeavor is a monitoring strategy which is timely, informative, accurate and comprehensive. There are some within and outside this Agency who question the efficacy of a separate monitoring activity at the Headquarters level in EPA. Among the reasons cited in support of this argument is the lack of reference to monitoring in any of the environmental acts passed by Congress. Happily, Congress is now recognizing this deficiency and taking corrective action. For example, the new Clean Water Standards Act, recently approved in the

Senate by unanimous vote, for the first time establishes a monitoring function for the Environmental Protection Agency allowing this Agency to directly monitor the outfall from industrial plants and municipalities into our rivers, lakes and coastal regions. Because of this it is evident that the Administrator will want monitoring identified at the highest possible headquarters level in EPA. It was, after all, for this reason that he established my office by EPA Order 1110.22, dated August 17, 1971. I am confident that the Congressional action is not an isolated event; we can look forward to statutory requirements for monitoring in air and all the categorical programs as well.

The monitoring requirements placed on EPA imply a highly sophisticated sensor network extending into all the regions, but coordinated through a central instrumentality, known as the Office of Monitoring. Briefly, our role is to give programmatic guidance for an overall monitoring strategy. What do I mean by programmatic guidance? Programmatic guidance entails many things but some of the more important elements would surely include the following:

a) To provide effective technical, administrative and logistical support to the regional surveillance and enforcement divisions.

b) To establish guidelines for the establishment of environmental baselines to identify environmental quality trends.

c) To establish guidelines for timely incorporation of newly developed monitoring techniques and equipment into regional monitoring networks.

d) To establish guidelines for identification of short-term and long-term monitoring requirements.

e) To provide specialized laboratory and field support as required.

f) To establish standards for methods and instrument performance for regional applications.

g) To assure utilization of state-of-the-art sensors, techniques, procedures and methods.

h) To operate a data transmission network linking automated in situ and remote sensors with regional and national data centers.

All these functions, and there are many others, spell out the role of the Office of Monitoring and its relationship with other units in EPA, particularly the regions.

However, all the activities I have enumerated rest on the premise of a vigorous and competent sensor technology program. In fact, I would venture to say that only through a reliable, efficient and timely monitoring program based on the most advanced concepts in sensor technology will the EPA be able to meet the challenge of creating and maintaining a healthful environment for present and future generations.

Historically, the routine monitoring of environmental pollutants has involved analysis of selected samples collected "in the field." Such sampling techniques are not only time consuming, but more important, they have very limited utility considering the vast geographic areas and pollution sources that must be monitored for truly effective environmental monitoring. Clearly, the routine sampling of environmental quality can only be effectively conducted through automated in situ or remote sensing instruments which function in the real-time mode.

Needless to say, an operational network of in situ and remote sensing instruments, to be widely deployed and effective, must consist of elements which are relatively inexpensive, reliable, sensitive, accurate, pollutant-specific and easily maintained and calibrated. Instruments which satisfy all these criteria simply do not exist for many environmental pollutants. A major contribution of these Workshops will be to pinpoint where further instrument development is required.

Ultimately, the acceptance of advanced monitoring systems such as we will be discussing rests on the intrinsic performance of the sensors and instruments and the degree to which they satisfy the aforementioned requirements. Although many advancements in sensor technology have occurred in recent years, the ideal remote or automated sensor has yet to emerge, and future sensor development will be of great concern to us. This is particularly so in areas of electro-optical instrumentation involving correlation or matched filter techniques and derivative spectrometry, and the new class of electro-chemical probes using ion selective electrodes where truly revolutionary developments are occurring in sensor technology.

Looking to the future, it is essential that the evolution of sensors be closely followed and strongly supported by EPA because even newer generations of sensing instruments will almost certainly radically affect techniques for monitoring environmental quality.

We have assembled here at these Workshops the leading exponents and proponents and possibly opponents of environmental sensor technology to discuss problems which are fundamental to an effective monitoring program. I am confident that the results of these meetings will constitute an important contribution to EPA's future monitoring strategy.

PART II

B. Opening Remarks

OPENING REMARKS

Donald C. Holmes
Director, Monitoring Techniques Division
Office of Research and Monitoring
Environmental Protection Agency
Washington, D. C.

Thank you, Will, for having set the theme for this Workshop. As General Chairman, I hope with everyone's cooperation and active participation to bring reality to some of those points in the next few days. The primary purpose of this first EPA Sensor Workshop is to review the present state of the art of remote and in situ sensors. In the process we may determine which sensor techniques are likely prospects for utilization within the ten EPA regions in performance of their responsibilities.

Monitoring the environment is a key to effective management for environmental quality. It is nearly impossible to detect environmental changes, desirable or undesirable, natural or man-made, without established base lines and repeated observations. Measurements are essential for the identification of environmental needs and the establishment of program priorities, as well as for the evaluation of program effectiveness, and they provide an early warning system for environmental problems which allows corrective action to be taken.

The choice of appropriate environmental monitoring systems presents some problems themselves: coverage of systems, both geographically and as to pollutants or parameters, measured, must be adequate: sensors should be optimally located: measurement instruments have to be accurate and calibrated to ensure compatibility of data from one location to another. All of these essential features must support the need to collect and analyze environmental data on a near real-time basis.

Without all of these capabilities, we cannot accurately determine our severest problem or a cost-effective method of attacking it. Nor can we evaluate the success of our efforts. Monitoring is not a substitute for action, but action without the knowledge provided by adequate monitoring is more likely to be ineffective.

In order to help achieve the purpose of this Workshop, it has been organized so that the participants will be given presentations in terms of the Agency's responsibility for the total environment. Though the tutorial speakers will address a particular area, it is incumbent upon the participants to perform the necessary integration so we consider the sensor systems requirement from a total environmental point of view. We have purposely limited the number of participants to encourage participation. We do have excellent participation from our ten Regional Administrators and from the three NERC's. It is my pleasure to welcome the representatives from the other Federal agencies who are working in allied sensor fields and who have come to discuss their activities with respect to environmental sensors.

We are planning on holding eight panel sessions, two concurrently at each of the four workshops. Time does not permit each of the panel sessions to be held sequentially. We have arranged to assign participants to the several panels so that associates from the same organization will attend the concurrent sessions. As a further aid to communication, I have asked each of the panel chairmen to present a 15-minute summary with recommendations and requirements from their respective panels on the last day of the Workshop. It is my interest to distribute the tutorial papers, written summaries, overall summation and appropriate recommendations, in the form of a Workshop Report.

The Workshop Steering Committee has prepared a discussion guide for each of the panel sessions. We certainly welcome additional topics from the participants.

Please note a few changes and additions to the Agenda as published. Mr. Jim Regan, EPA, will chair panel session A of Workshop III, and Mr. Ronald Sandwina, representing the Office of Civil Defense, will present a closing paper, emphasizing potential areas of cooperation between OCD and EPA. There are two tours of WERL planned, one today to observe EPA aircraft capabilities, and one at the close of the Workshop in the early afternoon on Thursday. There will be further information regarding these tours later in the program.

For your benefit at this Workshop, the Committee has assembled copies of professional papers presented recently regarding the sensing of environmental pollutants. These papers should be of interest and ought to help stimulate the discussions during the panel sessions. Now I would like to introduce the first of our tutorial speakers. Dr. Del Barth is the Director of NERC, Raleigh, N.C. Dr. Barth will speak to us on "Monitoring Needs for Air Pollution and Systems Required to Meet Those Needs."

Next we will hear from Dr. S. Q. Duntley, Director, Visibility Laboratories, Scripps Institute, San Diego, California. Dr. Duntley will discuss "Optical Methods for Detection of Water Pollution."

Finally this morning we will hear from Dr. Leonard Bowden, Chairman, Department of Geography, University of California, Riverside, California.

PART II

C. Tutorial Papers (3)

MONITORING NEEDS FOR AIR POLLUTANTS AND SYSTEMS REQUIRED TO MEET THOSE NEEDS

D. S. Barth & S. D. Shearer, Jr.
National Environmental Research Center
Research Triangle Park, N. C.

Prior to discussing appropriate sensors for use in air monitoring networks it is necessary to generally define the objectives to be achieved by various monitoring systems. Thus in the following we shall give first a broad discussion of various air monitoring objectives and then proceed to sensor which may be used for the various applications.

Air monitoring sampling devices may operate continuously or intermittently; they may collect integrated samples which may be analyzed at a laboratory or they may collect samples and analyze them simultaneously; they may give a digital reading on a dial, an analog printout on a recorder chart or a digital readout on computer tape; they may measure air concentrations at single locations or they may measure air concentrations over some specified integrated path length. Resulting monitoring data may be used for regulatory purposes or for research purposes or for some combination of both.

In general, the following objectives of air monitoring systems may be defined:

1. Regulatory purposes--Air quality measurements are required to determine compliance with primary and secondary national ambient air quality standards. Stationary source emissions must be measured to determine compliance with emission standards set as parts of implementation plans, or national emission standards for hazardous air pollutants or standards of performance for new sources for specified categories of industry. Mobile source emissions must be measured to determine compliance with national emission standards. For all of these applications a reference measurement method must be defined when the standard is set. The reference measurement method, or an equivalent one, must be used for each regulatory application.

2. Establishment of baselines and trends--Baseline air quality measurements must be established for all significant air pollutants for both rural and urban locations. Trends of these baseline measurements must be followed as a function of time to determine quantitatively what changes result as the number of sources changes or as air pollution controls are instituted. Inherent to this objective is the need for a systematic approach to the detection, identification and quantitation of new or newly recognized air pollutants. In many cases the development and application of new measurement methods are essential ingredients to achieve this objective.
3. Inventory of air pollution sources--Stationary and mobile man-made sources of all significant air pollutants as well as natural or man-made sources must be identified and measured on a nationwide scale. This inventory must be periodically updated. Emission factors may be estimated from process weight and material balance considerations or perferably measured with suitable source sampling and measurement methods. For this application as for all source measurement applications it is often more difficult to obtain a representative sample than it is to analyze the sample.
4. Exposure and effect data--Such data may cover a wide range of effects such as corrosion of selected materials, soiling, atmospheric turbidity, pH of precipitation, damage to growing vegetation, etc. It is essential to simultaneously measure the concentration of the air pollutant or pollutants of importance at the receptor over the time during which a specific effect is being measured on the same receptor. In this fashion it is possible to obtain data on the basis of which exposure-effect relationships may be constructed. From these relationships it is possible to determine to what concentrations air pollutants must be reduced to reduce a correlated adverse effect to an acceptable level. Clearly adequate accurate measurement methods must be available or be developed to measure both exposure and effect.

5. Development or validation of predictive models--Predictive models are necessary tools to allow calculations of required air pollution source reductions to achieve specified reductions in air quality measurements. This application requires as a minimum the simultaneous measurement as a function of space and time of sources, air quality and all meteorological parameters of importance. When important removal processes or chemical or physical transformations take place, adequate measurements must be taken to define the concentration changes which take place for the pollutants of interest.
6. Emergency situations--For instances where air pollution episodes or accidents resulting in release of dangerous air pollutants occur, it is necessary to monitor air pollution concentrations so that adequate protective action may be taken prior to the occurrence of substantial endangerment to human health.

All of the monitoring objectives described briefly above require the availability of field sampling devices and analytical measurement methods of known precision and accuracy. Effects of changing meteorological factors such as temperature and humidity and any interfering substances must be known. Calibration procedures for the measurement methods must be available and an adequate system for quality control must be instituted and maintained.

In the following some of the principal kinds of sensors available for use in the general applications for monitoring cited above will be discussed. Particular attention will be given to remote sensing devices. No attempt will be made to give an exhaustive coverage of the total field of available sensors. It is hoped that any important sensor inadvertently omitted from our consideration will be picked up during one of the subsequent workshops at this meeting.

REMOTE SENSING

Introduction

Remote sensing is usually thought about in terms of remote sensing from satellites and/or aircraft and will be the subject primarily covered in this section of the paper. However, we would like to encourage you in the various workshops at this meeting to think of remote monitoring in a broader concept. We have listed below four areas which we feel the term "remote sensing" encompasses.

a) Sensing of atmospheric pollutants from satellites and/or aircraft.
b) Sensing of atmospheric pollutants from ground-based remote instruments with the telemetering of data to a central point.
c) Sensing of emissions from stationary sources. Work currently underway in this area is being directed along three avenues:
    (1) Sensing of emissions as they emerge from the stack,
    (2) Sensing of emissions in the stack by "outside-the-stack" sensors, and
    (3) Long-path sensing of emitted pollutants.
d) Sensing of pollutant effects on ecology by remote means.

In addition, we need also to carefully define and base remote sensing on the needs and uses to which data obtained is to be put. Therefore, such sensing should probably be geared around the following purposes.

a) Global and/or worldwide transport of pollutants.
b) National pollutant trends and variations.
c) Monitoring to determine changes in environmental pollution as a function of control measures and as a check on compliance with pollution control requirements.
d) Monitoring to determine pollutant effects (human and ecological) in special localized areas.

The types, sophistication, and versatility of remote sensing instrumentation will vary widely depending on which of the above items are paramount. It is hoped that the various workshops associated with this meeting will give detailed consideration and discussion to the above mentioned ideas and thoughts.

MONITORING AND SENSING OF AIR POLLUTANTS

At this point it is in order to give a general brief discussion of the current state of the art of air monitoring and then present a brief review of developing areas in the remote sensing of air pollutants.

Current Air Monitoring Technology - Traditionally, the gathering of information regarding air pollutant concentrations in the environment has been directed toward a relatively few air contaminants known to be detrimental to human health and welfare. Such information has been used primarily by local, state, and federal agencies in their enforcement and regulatory functions.

This information has been gained through monitoring activities ranging from national networks designed primarily to determine long-term nationwide and state trends and averages to small intensive short-term activities designed for specific problem solving in certain localized areas.

A recent article(1) by Hochheiser, Burmann, and Morgan has well described the current state of the art in air pollution monitoring. In this article they state that the "methods and instruments for measuring air pollutants must be carefully selected, evaluated, and standardized." They list eleven factors which must be considered. These factors, given below, could apply equally well whether one was considering remote or traditional sensors.

a) Specificity--does the method respond only to the pollutant of interest in the presence of those other substances likely to be encountered in samples obtained from ambient air or pollution sources?

b) Sensitivity and range--is the method sensitive enough over the pollutant concentration range of interest?

c) Stability--is the sample stable? Will it remain unaltered during the sampling interval and the interval between sampling and analysis?

d) Precision and accuracy--are results reproducible? Do they represent true pollutant concentration in the atmosphere or source effluent from which the sample was obtained?

e) Sample averaging time--does the method meet the above-stated requirements for sample-averaging time of interest?

f) Reliability and feasibility--are instrument maintenance costs, analytical time, and manpower requirements consistent with needs and resources?

For continuous automatic monitoring instruments, further requirements must be considered:

g) Zero drift and calibration--is instrument drift over an unattended operation period of at least three days slight enough to ensure reliability of data? Are calibrating and other corrections automatic?

h) Response, lag, rise and fall time--can the instrument function rapidly enough to record accurately changes in pollutant concentration that occur over a short time in the sample stream being monitored?

i) Ambient temperature and humidity--does the instrumental method meet all of these requirements over temperature and humidity ranges normally encountered?

j) Maintenance requirements--can the instrument operate continuously over long periods with minimum down time, maintenance time and maintenance cost? Is service for the instrument available in the area of use?

k) Data output--does the instrument produce data in a machine-readable format?

Tables 1 and 2 present a concise summary of the current state of the art in traditional air pollutant monitoring for the common air pollutants. Table 1 is a list of sampling and analytical methodology for other important air pollutants and an indication of where major improvement is needed.

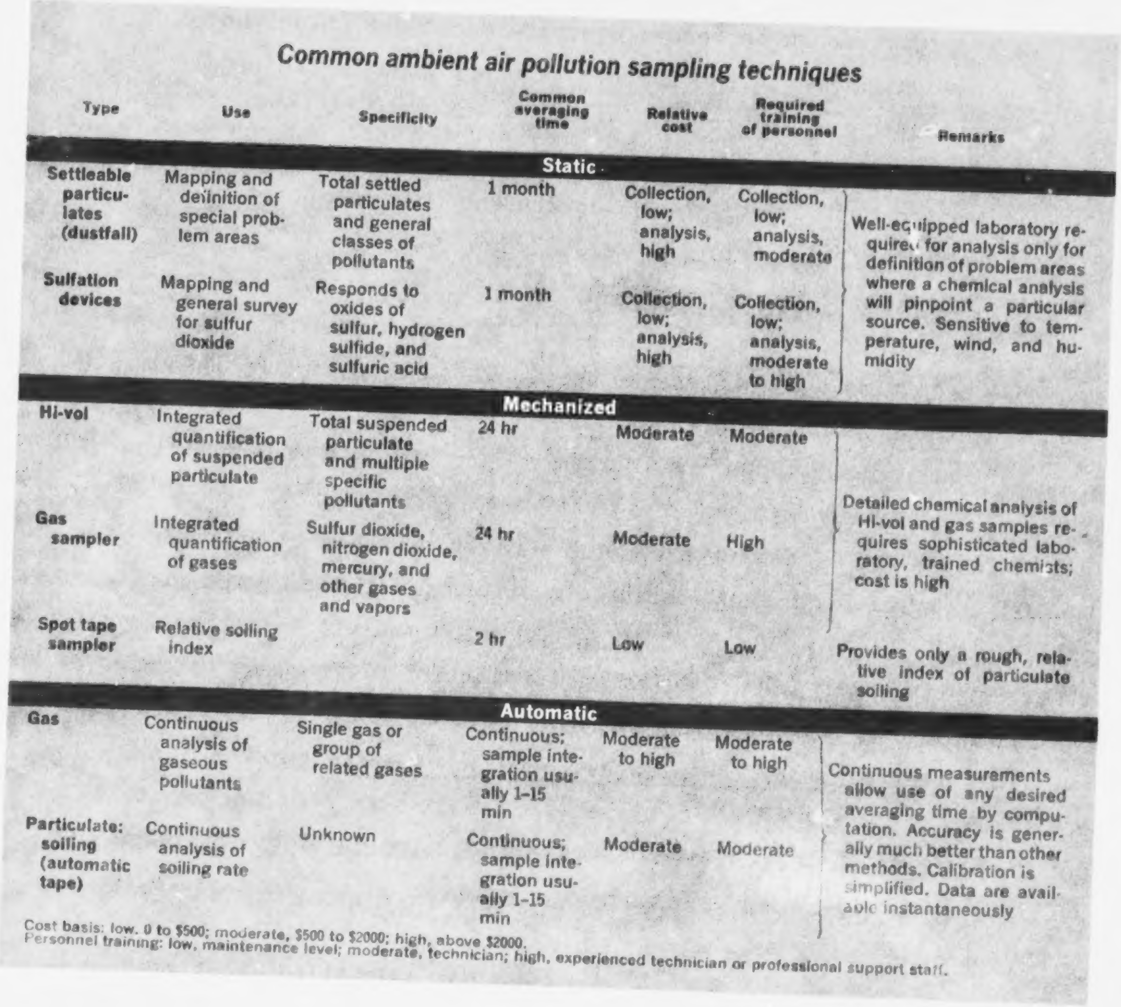
Pollutant Sensing from Aircraft/Satellites - The sensing of air pollutants from aircraft and/or satellites pose many varied problems not encountered with traditional monitoring. The majority of techniques utilized to date with success have been restricted to short-range (several kilometers) sensing.

Ludwig, Bartle, and Griggs(2) carried out a detailed study of several remote sensing techniques. In their study they considered in detail the applicability of the following instruments:

a) The ordinary dispersion type spectrometers,

b) Filter wedge spectrometers,

Table 1



Common ambient air pollution sampling techniques

Type	Use	Specificity	Common averaging time	Relative cost	Required training of personnel	Remarks
Static						
Settleable particulates (dustfall)	Mapping and definition of special problem areas	Total settled particulates and general classes of pollutants	1 month	Collection, low; analysis, high	Collection, low; analysis, moderate	Well-equipped laboratory required for analysis only for definition of problem areas where a chemical analysis will pinpoint a particular source. Sensitive to temperature, wind, and humidity
Sulfation devices	Mapping and general survey for sulfur dioxide	Responds to oxides of sulfur, hydrogen sulfide, and sulfuric acid	1 month	Collection, low; analysis, high	Collection, low; analysis, moderate to high	
Mechanized						
Hi-vol	Integrated quantification of suspended particulate	Total suspended particulate and multiple specific pollutants	24 hr	Moderate	Moderate	Detailed chemical analysis of Hi-vol and gas samples requires sophisticated laboratory, trained chemists; cost is high
Gas sampler	Integrated quantification of gases	Sulfur dioxide, nitrogen dioxide, mercury, and other gases and vapors	24 hr	Moderate	High	
Spot tape sampler	Relative soiling index		2 hr	Low	Low	Provides only a rough, relative index of particulate soiling
Automatic						
Gas	Continuous analysis of gaseous pollutants	Single gas or group of related gases	Continuous; sample integration usually 1–15 min	Moderate to high	Moderate to high	Continuous measurements allow use of any desired averaging time by computation. Accuracy is generally much better than other methods. Calibration is simplified. Data are available instantaneously
Particulate: soiling (automatic tape)	Continuous analysis of soiling rate	Unknown	Continuous; sample integration usually 1–15 min	Moderate	Moderate	

Cost basis: low. 0 to $500; moderate, $500 to $2000; high, above $2000.
Personnel training: low, maintenance level; moderate, technician; high, experienced technician or professional support staff.

Table 2

Commercial continuous monitoring methods for common air pollutants[a]

(Not an exhaustive list; without recorder)

SO_2 instruments—cost range, $2000–5000

Manufacturer	DETECTION PRINCIPLE Colorimetric	Coulometric	Flame photometric	Electrochemical	Conductimetric
Atlas Electric Devices Co.	■	■			
Barton Instr. Corp.		■			
Beckman Instr. Co.		■			■
Bendix Environmental Sci. Div.			■		
Calibrated Instr .Inc.					■
Combustion Equipment Associates					■
Davis Instrument Co.					■
Devco Engineering					■
Dynasciences				■	
Environmetrics Inc.				■	
Erickson Instruments				■	
Instrument Devel. Co.				■	■
Intertech Corp.				■	■
Kimoto					■
Leeds & Northrup					■
Meloy Labs			■		
Monitor Labs Inc.	■				■
Phillips Electronic Co.		■			
Pollution Monitors Inc.	■				
Precision Scientific	■				
Process Analyzers Inc.		■			
Scientific Industries					■
Technicon Corp.	■				
Tracor Inc.			■		
Wilkens-Anderson Corp.	■				

Oxidant instruments—cost range, $1000–7000

Manufacturer	DETECTION PRINCIPLE Colorimetric	Coulometric	Chemiluminescence	Uv absorption
Atlas Electric Devices Co.		■		
Beckman Instrument Co.	■	■		
Bendix Environmental Science Div.			■	
Dasibi Corp.				■
Mast Development Co.		■		
McMillian Electronics			■	
Monitor Labs Inc.	■			
Ozone Research		■		
Raditron Inc.	■			
REM Inc.			■	
Spectrometrics of Florida Inc.				■
Technicon Corp.	■			
Triangle Instrument Co.			■	

CO instruments—cost range, $2500–5000

Manufacturer	DETECTION PRINCIPLE NDIR	Uv (mercury replacement)
Bacharach Instrument Co.		■
Beckman Instrument Co.	■	
Bendix Environmental Sci. Div.	■	
Calibrated Instrument Co.	■	
Intertech Corp.	■	
Morgan Co.	■	
Mine Safety Appliance Co.	■	

Total hydrocarbons—cost range, $2000–5000

Manufacturer

Beckman Instrument Co.
Bendix Environmental Science Div.
Davis Instrument Co.
Delphi Industries
Mine Safety Appliance Co.
Power Design Inc.

(all based on flame ionization detection)

Methane-CO-total hydrocarbon instruments —cost, approximately $10,000 with recorder

Manufacturer

Beckman Instrument Co.
Mine Safety Appliance Co.
Tracor Inc.
Union Carbide Corp.

(all based on gas chromatographic separation and flame ionization detection)

NO_2-NO_x instruments—cost range, $2000–5000

Manufacturer	DETECTION PRINCIPLE Colorimetric	Coulometric	Electrochemical
Atlas Electric Devices Co.	■		
Beckman Instrument Co.	■	■	
Dynasciences			■
Environmetrics Inc.			■
Mast Development Inc.		■	
Monitor Labs Inc.	■		
Intertech Corp.			■
Pollution Monitors Inc.	■		
Precision Scientific	■		
Raditron Inc.	■		
Scientific Industries	■		
Technicon Corp.	■		
Wilkens-Anderson Corp.	■		

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[a] Mention of companies or products does not constitute endorsement by the Environmental Protection Agency.

Table 3

Other pollutant sampling and analytical methods

Pollutant	Sampling method	Analytical method	Major improvement needed
Hg	Gas bubbler, Hg amalgamation	Flameless atomic absorption, uv absorption	Yes
Be	Hi-vol	Emission spectroscopy, atomic absorption	No
Asbestos	Membrane filter sampler	Electron microscopy	Yes
Pb	Hi-vol	Emission spectroscopy	No
Cd	Hi-vol	Atomic absorption, emission spectroscopy	No
As	Hi-vol	Colorimetric, neutron activation	No
Ni	Hi-vol	Atomic absorption, emission spectroscopy	No
Polynuclear organics	Hi-vol	Chromatography and fluorescence analysis	No
Polychlorinated biphenyl	Not developed	Not developed	Yes
F	Coated-open tubular column	Specific ion electrode	Yes
Odor	Human odor panel	Olfaction	No
H_2S	Continuous automatic analyzer and mechanized tape sampler	Flame photometric, coulometric, colorimetric	Yes
Fine particulates	Impactor	Gravimetric	Yes
V	Hi-vol	Emission spectroscopy	No
Mn	Hi-vol	Emission spectroscopy	No
Cr	Hi-vol	Emission spectroscopy	No
Se	Not developed	Not developed	Yes
Cl_2	Not developed	Not developed	Yes
HCl	Not developed	Not developed	Yes
Cu	Hi-vol	Emission spectroscopy, atomic absorption	No
Zn	Membrane filter sampler	Emission spectroscopy, atomic absorption	No
B	Not developed	Not developed	Yes
Ba	Membrane filter sampler	Emission spectroscopy	Yes
Sn	Hi-vol	Emission spectroscopy	No
P	Not developed	Not developed	Yes
Li	Not developed	Not developed	Yes
Aeroallergens	Not developed	Not developed	Yes
Reactive organics	Not developed	Chromatography	Yes
Pesticides	Not developed	Chromatography	Yes
Radioactive materials	Hi-vol	Gross beta and gamma scanning	Yes

Table 4 Qualitative Comparison Among Spectroscopic Instruments for the Detection of Pollutants from Satellites

Instrument	Sensitivity	Specificity	Complexity Of Instrum.	Observ. Time	Information Content	Remarks
Radiometer (filter wheel or many single filters)	Medium	Low	Low	Short	Medium	Limit $\Delta\omega \sim 3$ cm^{-1}; many channels required
Radiometer (polychromator)	Low Medium	High Low	Medium	Short Short	Medium	Assuming $\Delta\omega \sim < 1$ cm^{-1} Assuming $\Delta\omega > 1$ cm^{-1}; Multiple detectors required
Scanning--Spectrometer	Low Medium	High Low	Medium	Long Medium	High	Assuming $\Delta\omega <$ cm^{-1} Assuming $\Delta\omega >$ cm^{-1}
Optical Correlation Instrument	High	High	Medium	Short	Medium	Matched filter with multiple entrance slits and nondispersive
Interferometer--Spectrometer	High	High	High	Medium	High	Sampling time at least 10 sec; image motion compensation required; large information content for wide spectral interval

c) Multiple detector spectrometers,
d) Scanning spectrometers,
e) Interferometer spectrometer (Michelson type),
f) Correlation spectrometer,
g) Matched filter spectrometer with multiple entrance slits,
h) Selective chopper radiometer, and
i) The cross correlating spectrometer.

Table 4 presents a qualitative comparison of several spectroscopic instruments taken from the report by Ludwig. The conclusions of Ludwig, et at, regarding the detection of air pollutants by remote sensing from the ultraviolet (0.25 to 0.40 micron) to the microwave (greater than 500 micron) region were as follows:

- The ultraviolet visible region has more disadvantages.
- The infrared region (3.5 - 13u) has more advantages than disadvantages
- The microwave region (0.1 - 3 cm) is not useful because of lack of specificity, and
- The quantitative measurements of aerosol content in the lower atmosphere probably cannot be made from a satellite.

Table 5 (also from Ludwig, et al) lists the advantages and disadvantages of remote sensing in the ultraviolet and infrared regions.

Table 5, Advantages and Disadvantages of Spectral Regions

	Spectral Range	
	0.3 - 3.5u	3.5 - 13u
a. Time of observation	Daytime	Day and nighttime
b. Factors affecting observation	Rayleigh and Mie scattering from the atmosphere	Meteorological conditions such as surface temperature and temperature profile through the atmosphere
c. Methods of over coming affecting factors	Not possible by direct measurement; maybe thru theoretical calculations	Possible by direct measurements from satellite and/or through global weather-station network
d. Radiative active species	NO_2, SO_2,O_3 (weak)	All molecules

Altshuller and McCormick[3] recently presented an article on remote sensing platforms for air pollution. This paper is an excellent review of the relative application of aircraft and satellites for remote sensing. Table 6 from their paper presents a summary of problem areas in remote sensing utilizing these two types of platforms.

> "With so many limitations on satellite applications to air pollution measurement, it is clear that available resources should be used to exploit aircraft not satellite measurements. Measurements from aircraft can be made more rapidly, more effectively and at a lower overall cost for air pollution applications within urban areas or air quality regions."

Hanst[4] has presented a rather comprehensive discussion of infrared spectroscopy and infrared lasers in air pollution research and monitoring. Table 7 presents a summary given by Hanst of the detection of pollutants by absorption of laser radiation.

For those interested in more technical details of remote sensing, the publications by Leonard[5] and McClintock, et al[6] and the recent book edited by Pitts and Metcalf[7] are particularly useful in addition to the ones mentioned previously. In the various workshops of this meeting much more detail will be given regarding the specific advantages and disadvantages of specific monitoring requirements.

REMOTE SENSING VERSUS MONITORING NEEDS

It must be emphasized that the development and use of remote sensors must be tied very closely to the monitoring and surveillance needs in order to insure that valid and useful data result. Before significant resources are expended the monitoring requirements must be clearly defined for the various EPA program needs. In regard to the requirements of atmospheric monitoring the prime emphasis must be directed toward meeting the legal mandates of the 1970 Clean Air Act Amendments.

Table 6 Remote Sensor Satellite/Aircraft Applications

	PROBLEM AREA	SATELLITE APPLICATION	AIRCRAFT APPLICATION
1.	Choice of instrument	Priority decision must be made well in advance	Various instruments may be flown separately or in combination as they are developed.
2.	Instrument malfunction	If irreversible, complete failure results.	Instrument can be returned to ground for repair or modification.
3.	Instrument	Appears limited to use infrared region.	Ultraviolet, visible, and infrared regions and point-sampling can be used.
4.	Frequency of measurement	In a polar orbit a satellite is over a given urban area for only a very short time each day.	Repeared sweeps in a variety of patterns can be made to obtain diurnal variations in concentration.
5.	Resolution	A 10 by 10 mile resolution is considered good, but even this resolution is marginal with respect to measurement output desired over urban areas. Resolution in third dimension or in time is unlikely or impossible.	Satisfactory resolution in time and space is possible.
6.	Effect of temperature and pollutant profile	Quantitative measurements depend on concurrent measments of surface temperature, temperature profile, and estimate of pollutant profile	The two factors do not affect many types of measurements possible; temperature can be determined directly and concurrently without difficulty.
7.	Clouds or overcast	Measurements lost. This is a very serious problem in terms of day by day measurement over specific urban areas.	Within energy limitations on instrument and flight minimums, measurements can be made below clouds or overcast.

TABLE 7 DETAILS ON DETECTION OF POLLUTANTS BY ABSORPTION OF LASER RADIATION

Pollutant	Source	Location of ir band centers (u)	Laser line to be used	Concentration in parts per million to give 5% signal change over a 1 km path (estimated)	Remarks
CH_4	Marsh gas	3.35,7.7	He-Ne--3.39	0.03	Naturally in the air.
C_2H_2	Auto exhaust, combustion	13.7	Ne?	----	Very strong absorption
C_2H_4	Auto exhaust combustion	10.52	CO_2--10.53	0.02	Distinctive spectrum, strong Q-branch.
C_4H_{10}	Many, including auto exhaust	3.4	I_2---3.43	0.05	C-H band is a measure of total organics.
PAN	Atmospheric photochemistry	5.4,7.8	He-Ne?	0.05	Other bands are available
NO	Auto exhaust, combustion	5.3	I_2--5.5	0.5	Iodine line will penetrate humid atmosphere
NO_2	Auto exhaust combustion	3.4, 6.2	Rare gas?	----	A difficult case due to water interference.
CO	Auto exhaust, combustion	4.7	I_2 --4.86	2.0	Some other laser line could make detection more sensitive.
O_3	Atmospheric photochemistry	9.6	CO_2--9.5	0.05	One of the simplest cases.
SO_2	Burning of sulfur-cont. fuels	7.3,8.7, 18.5	Ne--7.4	0.03	Needs work to find better laser line.
NH_3	Organic wastes, industry	10.5	CO_2--10.7	0.02	Very strong lines at about 10.3 and 10.7
H_2S	Industry	2.6,7.7	Kr?	----	
HF	Burning of plastics	2.3	Kr?	----	
HCl	Burning of plastics	3.6	Xe?	----	
D_2O	Atomic energy installations	3.7	Xe	----	

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OPTICAL METHODS FOR DETECTION OF WATER POLLUTION

S. Q. Duntley
Visibility Laboratory
Scripps Institution of Oceanography
University of California, San Diego

There is little doubt that standard, analytical, chemical techniques for water analysis supplemented by laboratory biological tests provide the most accurate and reliable source of knowledge concerning pollutants in natural waters, but these techniques are slow and expensive. They require water samples to be obtained and returned to a laboratory for for specialized laboratory equipment to be brought to each water location. Optical techniques are faster and adaptable for use in the field, but not all kinds of pollutants can be detected or their concentrations measured by optical means. In some cases optical detection can be done from aircraft and even from spacecraft. It is not the purpose of this talk to catalog every optical technique nor to discuss specific commercially available devices. Rather, I shall speak about certain principles which underlie the more promising optical methods.

This audience is doubtless familiar with the available standard works which describe analytical chemical techniques for water quality determination. You also know that the research committee of the Water Pollution Control Federation publishes each year a literature review of new analytical methods. More than 600 papers involving new methods have appeared in the last three years, and some of them are optical techniques. Most of the new methods stress speed and state that it is a critical factor in pollution studies. Many of the new laboratory methods are no more accurate than older ones but they are faster.

Among the new optical methods are found spectroscopic techniques for the detection of phenol or petroleum in water. There are spectrochemical techniques for copper, lead, zinc, nickel, chromium, aluminum, iron and manganese as well as for the alkali metals. Aluminum can now be assayed by fluorometry, a can phosphates. The oxygen content of water can be assayed by new chromatographic techniques as well as by new ultraviolet absorption methods. There are new fast colorimetric determinations for chromium, cobalt, and aluminum as well as for organic acids and for the measurement of ph and alkalinity. Chromatography has also been used for measuring pesticides in water, herbicides and organic acids as well as petroleum and phenol. Some of the new techniques involve continuous flow of devices with automatic recording of the pollutants and their concentrations.

Work has been done on contact sensors that can be anchored or mounted in bodies of natural water to analyze and record certain pollutant conditions. If desired, they can transmit their data to a central station by radio and even be interrogated by a data-collecting satellite system.

Later in this talk I will return to the topic of optical in situ monitoring devices and mention some very new optical approaches. First, however, let us consider some optical remote sensing techniques for water pollution. Those concerned with the quality of water in streams know that a discharge of pollution somewhere along a river often goes undetected until the material is many miles downstream and there is no indication from whence it came. Clearly, patrol of such rivers by aircraft equipped with proper photographic devices or other optical remote sensors offers a chance of finding the source of the pollution. Wherever large area coverage is essential, patrol by aircraft, perhaps even by spacecraft, may be the most effective procedure.

Airborne techniques have detected and measured pollutants, like oil, floating on water surfaces. One of the most graphic and sensitive methods is by photography or observation in the edge of the glitter pattern formed by reflection of the sun. Evidences of floating oil can be detected throughout the glitter pattern, but this rarely, if ever, is accomplished in a single photograph. This is because the dynamic range of photographic film is not sufficient to cope with the enormous range of glitter pattern brightness. With normal exposures the presence of floating oil appears as a pattern of dark streaks in the edge of the glitter pattern. Actually these are not great masses of oil, but thin layers floating upon the water surface. Why do thin oil streaks show so plainly in the edge of the sun glitter pattern? The reason goes back to an old adage of the sea which has to do with pouring oil on troubled waters. Mariners have known for a long time that rescue missions at sea involving life boats can be aided by pouring oil on the surface of the water to diminish the water waves. The surface tension of floating oil is significantly greater than that of a clean water surface. The interaction of wind with water to produce waves is governed by surface tension, particularly when the wind speed is low over the water surface. Whenever the wind blows, tiny wavelets appear due to elastic deformation of the surface tension layer. These tiny elastic waves involve much the same physical principles that are involved in the capillary rise of liquids in small tubes, and for this reason they are called capillary waves. They are quite different in almost every respect from large water waves in which energy is stored in the form of gravitational potential energy wherever the water rises and sinks as the waves progress. These large waves build up over a period of time as the wind blows and persist as rollers after the wind has died. Their slopes are small and their optical effect is minor when photographed from high-flying aircraft. The tiny capillary wavelets, however, are present almost instantly when the wind begins and vanish as quickly when it ceases. Their tiny facets are steep and, since the surface of the water is covered with them, they control the space-averaged reflectance characteristics of water. Thus, any floating substance which alters surface tension will alter the appearance of a windruffled water surface. The way this works is shown diagrammatically in Figure 1. Here an aerial camera looks vertically downward on the water surface. This is uniformly covered by capillary wavelets and illuminated by sunlight. If the fieldof view of the camera extended far to our right, it would record the center of the sun glitter pattern. If the water was calm, it would record a reflected image of the sun. But since the capillary waves are present it sees a large bright nearly circular pattern, brightest at its center where the solar reflection point is located. The brightness of the pattern diminishes rapidly toward all of its edges and the camera looking downward at th edge of this glitter pattern sees the water surface dark on our left but light a little further to our right.

Experiments have shown that, averaged over a large area of water surface containing thousands of individual wave facets, the fractional area of water surface tipped in any specified direction follows a nearly Gaussian distribution, in which flat, horizontal facets are the most common occurrence. At the solar reflection point, flat, horizontal facets reflect sunlight directly to the camera and because horizontal facets are so numerous, the water surface appears dazzlingly bright. Indeed each tiny horizontal water surface has the reflected brightness of the sun and may, therefore, be more than a million times brighter than any facet which reflects some other part of the sky. Directly beneath the camera, however, horizontal water surfaces reflect the sunlight too far to the left to enter the lens. Only surfaces having the proper tilt will mirror the sun and appear bright to the camera. The frequency of occurrence of facets tipped at just the right angle to fulfill the mirror condition is very much less common than horizontal surfaces.

The lower curve shows the fractional area of the water wave surface tipped properly to reflect sunlight to the camera lens. Although only a few of the tiny capillary wave facets at the middle point in Figure 1 fulfill this condition they are exceedingly bright and cause the average tone of the water to appear light on the photograph. At the left hand point, however, almost no facets are tipped sufficiently to fulfill the mirror condition. Thus, at this point in the picture the water surface appears dark. The lower curve is a Gaussian distribution having a variance which is proportional to the speed of the wind over the water surface. If the wind diminishes, the Gaussian curve will narrow. Any increase in surface tension will also make a corresponding narrowing of the Gaussian peak. That is to say, if the water surface is covered by a uniform layer of oil, the surface will be more calm and the distribution of slopes will be more narrow. If an oil film lies at the center point in Figure 1, the water will appear more dark to the camera because fewer facets are sufficiently steep to fulfill the mirror relation. Thus, in the idge of the glitter pattern a water surface having streaks or patches of floating oil appears bright where the water surface is clean and dark where it is calmed by floating oil.

The sensitivity of this mechanism for the detection of small amounts of oil on the surface of water is greatest where the Gaussian is steep. Interpretation is easiest in the extreme edge of the glitter pattern. If normal photographic exposures are used, there will be a comparatively small region of the photograph where streaks of oil on the surface of the water show prominently. This region is part of a circular band centered on the solar reflection point. The footprint of high sensitivity for detecting floating oil is limited to a rather small angular field. In the case of low altitude vertical photography, the amount of water surface it covers is ordinarily too small to be useful, but in the case of high altitude aerial photography a very practical area coverage can be obtained.

A complete photographic oil coverage survey of a river, lake, bay, or harbor can be made as follows:

An aerial camera of moderate size is equipped with panchromatic film, a red filter and an intervalometer set to take a series of vertical photographs with a large overlap (e.g., 70 o/o). It is flown over the water at high altitude on a clear day with the sun high in the sky. The pilot flies directly away from the sun on a course that carries the plane over the area of interest. The resulting series of pictures contain a succession of footprints of high sensitivity which can be combined in the form of a mosiac showing the distribution of oil floating over the entire surface of the water.

The sensitivity of the sun glitter method of oil survey may be one of its weaknesses. Like many other remote sensing techniques it requires a priori information on an in situ check to make sure that the oil is indeed of a harmful variety and of significant amount. Other remote sensing techniques can be employed to help the situation. For example, it is a fact that oil has a much higher reflectance in terms of ultra violet light than does a clean surface water. Thus, in ultraviolet imagery oil slicks appear white. Far infrared imagery also reveals the presence of oil on water but the interpretation is less simple because, depending upon temperature, the oil can appear either darker or lighter than the surrounding water. Thermal infrared (line-scan) imagery is best for pinpointing the source of an oil spill; ultraviolet imagery is best for indicating its extent, and shortwave solar infrared is useful for distinguishing the oil slicks from floating vegetation.

Aerial imagery of water surfaces that does not shown the sun glitter often reveals the presence of sub-surface materials. These may sometimes be pollutants or they may be indicators of pollution. For example, chlorophyll-bearing marine plants, usually microscopic in size, bloom wherever advantageous conditions of nutrients and sunlight occur. Photosynthesis occurring in these plants uses solar energy to produce food materials and liberate oxygen. In the deep ocean the presence of these phytoplankton may indicate rich fisheries and this is sometimes true of inland waters. On the other hand, the growth of green plants and water may indicate the presence of pollution and they may be responsible for eutrophication. From the standpoint of the present optical discussion, however, it is unimportant whether the presence of chlorophyll-bearing plants in water is good or bad. It is only important to know how their presence can be detected and reliably distinguished from quite different materials which may be present in natural waters.

Those who swim along the surface of water with a mask and snorkel, or those who have had the experience of riding in a glass bottom boat, know that the color of deep water as seen beneath the surface has many characteristic colors. Very clear water appears a beautiful luminescent blue, reminiscent of the clear zenith summer sky. When clear water contains an abundance of chlorophyll-bearing phytoplankton it may appear to be a rich green, while water containing silt may appear like coffee with cream. In shallow water, the bottom has a profound influence and the composite color depends not only upon the water and its contents but also upon the color of the bottom. Figure 2 illustrates two of these cases. The curve marked 0.1 represents blue-appearing, deep, clear ocean water containing only a small amount of chlorophyll-bearing phytoplankton. Vast areas of oceans are typified by water of this kind. There is some organic productivity and some fish are found, but not enough to make a rich fishery. At some other clear-water location where upwelling brings nutrients from the depths, there is a much larger standing crop of microscopic green plants. The daylight reflection spectrum as seen beneath the water surface is shown by the other curve on this slide. This depicts rich green water, having 100 times the chlorophyll concentration of the first curve.

Noncontact detection of chlorophyll by optical means would seem to be a simple matter on the basis of curves like those in Figure 2, but the spectrum can be complicated by the presence of silt, bottom influence, and colored products due to the decaying of plant and animal life in the water. Nevertheless, chlorophyll-rich water has certain distinctive spectral features which may enable a sufficiently definitive analysis to be made from measurements at a few wavelengths. Note that the two curves cross in the green region of the spectrum where the wavelength is near 520 nm. Curves representing intermediate concentrations of chlorophyll in clear water all pass through this same point. It is as if the curves were all hinged here. This means that a monochromatic measurement at this wavelength will be independent of the chlorophyll concentration. Such measurements provide an opportunity to allow for other water properties, the quantity of available daylight, sky reflections, atmospheric effects, and so on without regard to the presence or absence of chlorophyll. At shorter wavelengths, in the blue region of the spectrum, chlorophyll absorbs sunlight strongly and converts some of the absorbed energy into chemical potential energy through photosynthesis. It is this energy that is responsible for the production of oxygen and food materials. Clearly, increasing concentrations of chlorophyll-bearing phytoplankton cause the reflectance of the ocean to decrease in the blue region of the spectrum. Thus, measurements of reflectance in terms of blue light can be compared with the reflectance of the water at the "hinge" wavelength in the green in order to determine quantitatively the concentration of chlorophyll in water, provided no other colored substance is present to confuse the readings. In the deep oceans this is true more often than in bays, rivers, or lakes.

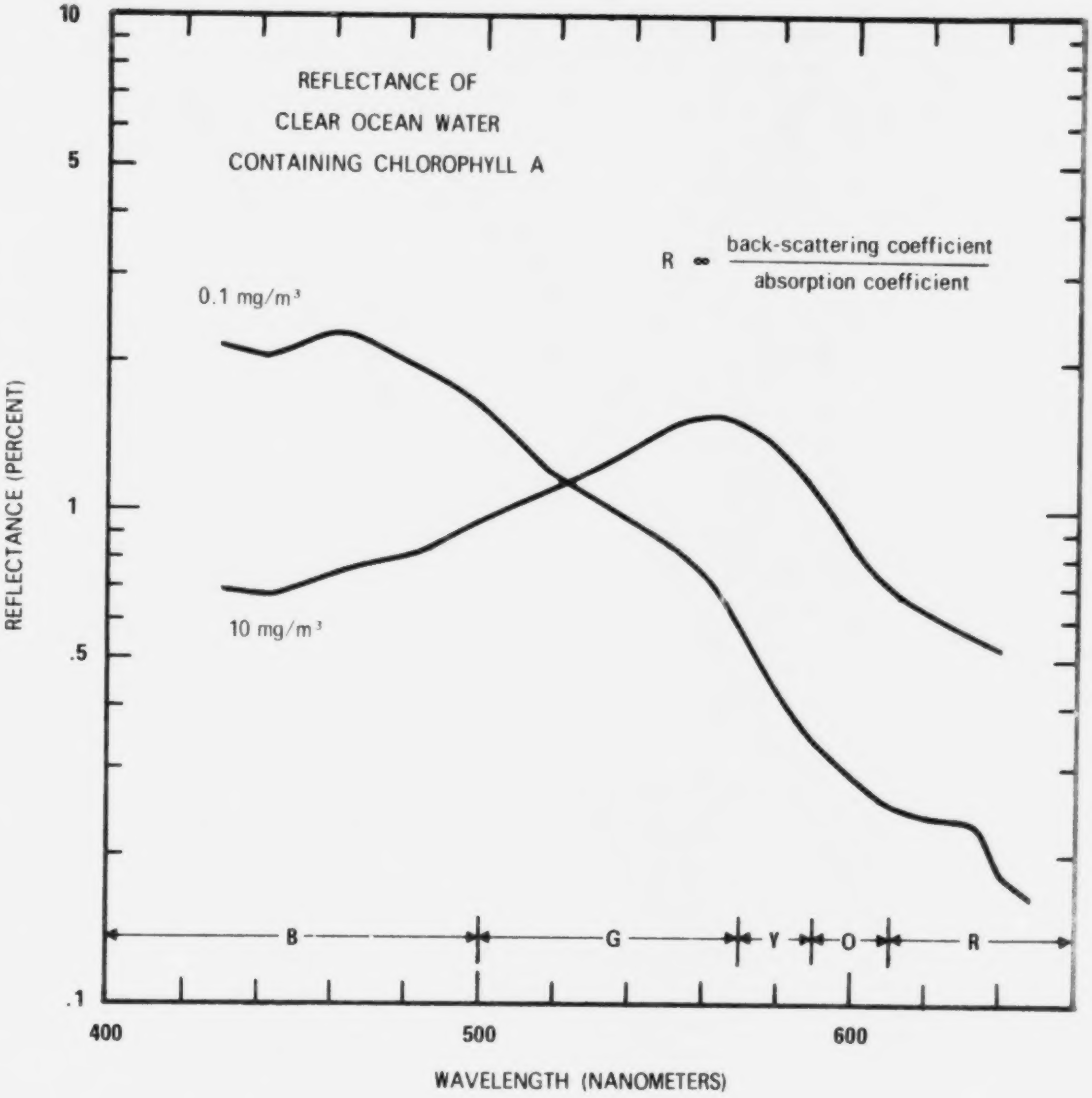
In the yellow-green part of the spectrum at, say, 560 nm the presence of phytoplankton causes the reflectance of water to rise. (See Figure 2.) This is because phytoplankton scatter light of this wavelength but do not absorb it. The interplay between absorption and scattering in sea water is a complex subject, treated ordinarily by methods of radiative transfer analysis. The equations are well known but complicated except in clear water cases where, to a useful engineering approximation, the spectral reflectance of deep water is linearly proportional to the ratio of the back-scattering coefficient for downwelling daylight to the total absorption coefficient. Figure 2 demonstrates that the addition of chlorophyll-bearing phytoplankton to sea water causes absorption dominated optical effects in the blue region of the spectrum and scattering dominated optical effects in the yellow-green, with a "hinge" point at 523 nm between. This is a unique set of spectral properties by means of which chlorophyll-bearing materials can be sensed in natural waters. A properly chosen three-wavelength differential spectroradiometric measurement (i.e., one involving ratios of spectroradiometric measurements at different wavelengths), contact or non-contact, should enable chlorophyll concentrations in water to be distinguished and assayed, even in the presence of most sediments, organic decomposition products, or industrial wastes.

Perhaps the most common optical technique using contact sensors for the identification and measurement of dissolved materials is absorption spectroscopy. Laboratory workers are usually familiar with techniques which employ small optical devices consisting of a lamp, a filter, a container for some fluid through which the filtered light passes and a photo-electric cell to measure the amount of light transmitted by the fluid. These are usually called abridged spectrophotometers. There are many makes on the market and a very wide variety of techniques for their use. All of these techniques are based upon the studies that have been made in research laboratories equipped with recording spectrophotometers that draw the complete spectral curve of the materials and work out the techniques involving filters which isolate points on these curves. No form of analysis or measurement can be fraught with more pitfalls than the use of abridged spectrophotometers which measure at only one or two wavelengths. If these instruments are used under circumstances in which the shape of the absorption spectrum is distorted by any unexpected substance or by any physical factor, such as a change in ph or temperature, drastic errors may be made. Research spectrophotometers which record spectral curves are expensive, but their use in the only sure way to avoid pitfalls in dealing with uncertain situations. Even so, the recognition and positive identification of a substance by the shape of its spectrophotometric curve is not easy when several absorbing substances are present. In such cases there is a useful but old technique, based upon a very well known principle that is often overlooked. The method is rigorous only in clear solutions, where scattering is very small compared with absorption. That is to say, fluids, which although colored, are clear. Then the transmittance T of a path of length x is given by the simple exponential expression e^{-acx}, where a is the absorption coefficient for a unit concentration and c is concentration. Spectrophotometers plot curves of transmittance versus wavelength for absorbing fluids. If a series of such curves are plotted corresponding with various concentrations, it will be found that the shapes of the curves are quite different. If the substance of interest is only one component in a mixture, its recognition may be very difficult. Some spectrophotometers produce curves in the form represented by the equation $\ln(1/T) = acs$. The ordinates of such curves are seen to be proportional to the triple product acx. Curve shape again depends upon concentration, and identification of components is nearly as difficult as before. If, however, spectrophotometric curves are represented by the equation

$$\ln \ln(1/T) = \ln a + \ln c + \ln x,$$

the curve shape is determined solely by the absorption coefficient a, because concentration c and thickness x do not vary with wavelength. In this form, components of mixtures can be identified with much greater certainty.

The complexities of organic absorption spectra and the scattering effects in fluids have posed major difficulties for those engaged in medical research. The quest for improvements in optical techniques of this kind will probably never cease, but it appears that an important breakthrough is occurring at present. I refer to derivative spectroscopy. That is to say, to analysis techniques based upon curves of the derivatives of the spectrum rather than the spectrum itself. It is often possible to separate and identify the optical characteristics of particular materials in the presence of interfering spectral signatures by employing the second derivative of the spectroradiometric curves. This can be illustrated in terms of the chlorophyll example used previously in this paper. Figure 3 shows two overlapped second derivative spectra: One is derived from the *in situ* reflectance curve in Figure 2 which relates to rich chlorophyll-bearing water having a concentration of 10 mg/cubic meter. For comparison there is reproduced a second derivative spectrum curve derived from airborne measurements with an airborne spectroradiometer flown at an altitude of 2500 feet above a chlorophyll-rich ocean area by Peter White, of the TRW Corporation. The remarkable similarity of White's curve in the green, orange, and red regions of the spectrum shows that the second derivative optical characteristics of chlorophyll-bearing phytoplankton are unperturbed by the sky reflection at the water surface and by atmospheric effects in the lower atmosphere. From the standpoint of non-contact sensing this is a very exciting result. The recent scientific literature demonstrates that derivative spectroscopy is exciting the life scientists. It may also open important possibilities for the optical detection and monitoring of pollution.


REFLECTANCE OF
CLEAR OCEAN WATER
CONTAINING CHLOROPHYLL A
R ∞ back-scattering coefficient / absorption coefficient
0.1 mg/m³
10 mg/m³
10
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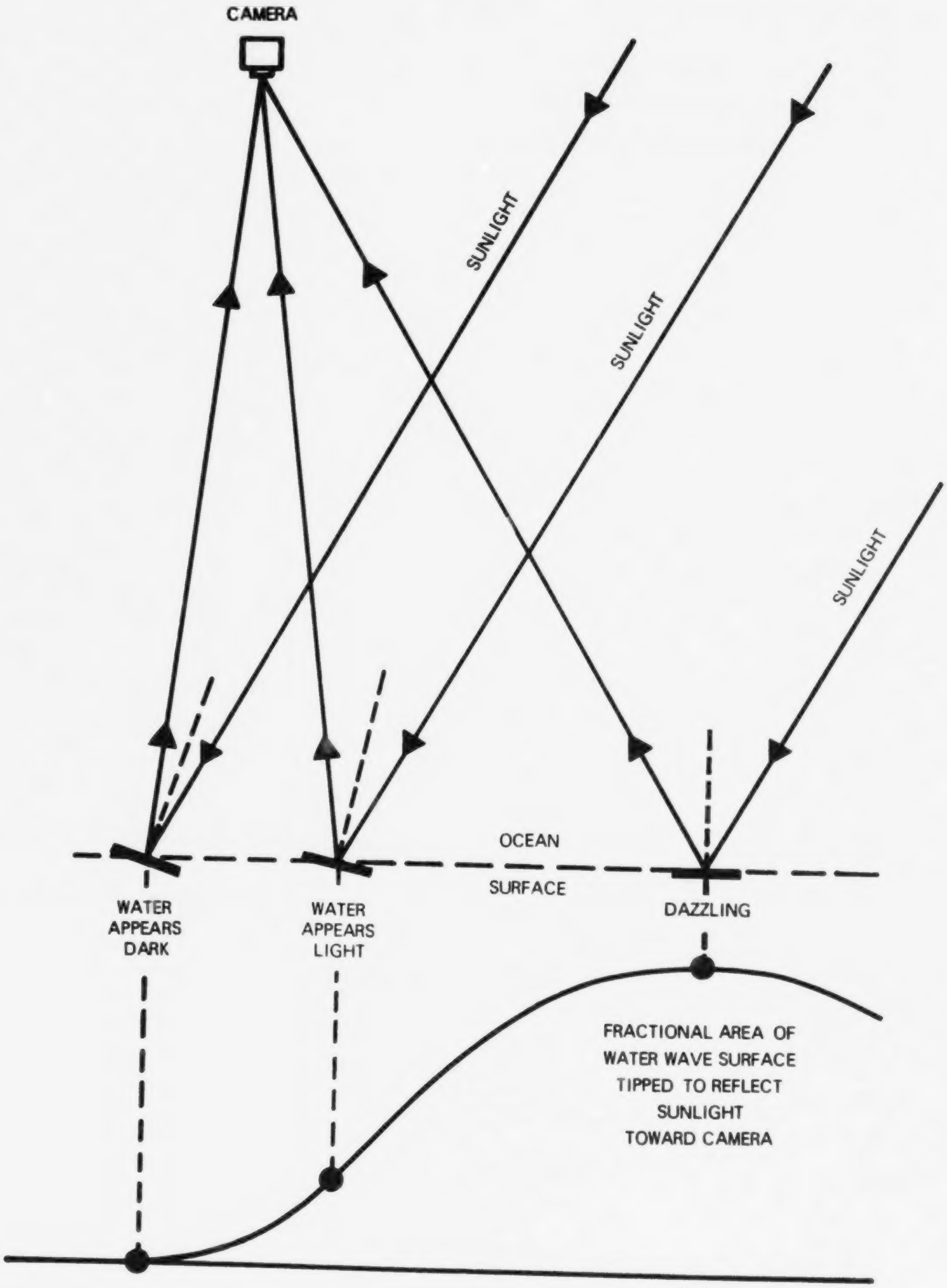
CAMERA
SUNLIGHT
SUNLIGHT
SUNLIGHT
OCEAN
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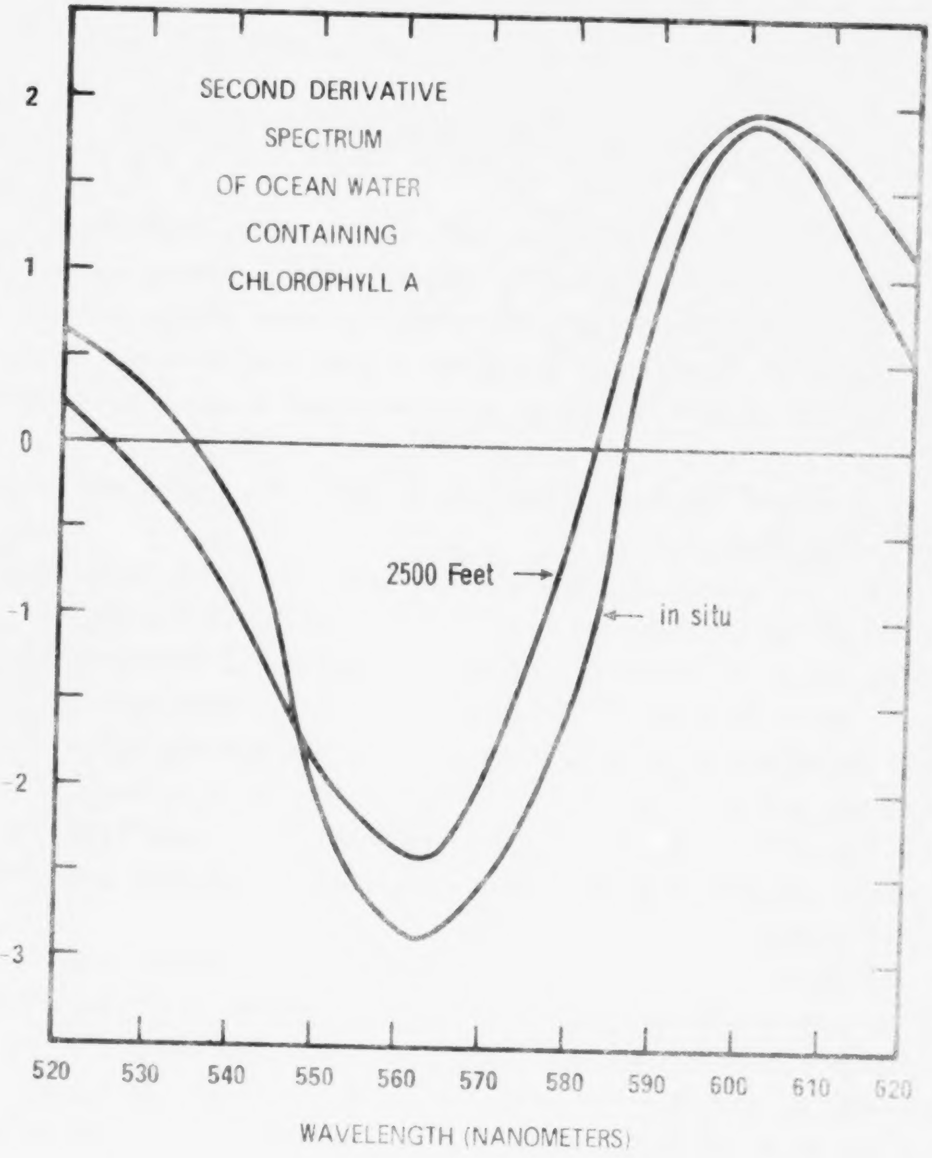
FRACTIONAL AREA OF WATER WAVE SURFACE TIPPED TO REFLECT SUNLIGHT TOWARD CAMERA


SECOND DERIVATIVE
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OF OCEAN WATER
CONTAINING
CHLOROPHYLL A
2
1
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590
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620
WAVELENGTH (NANOMETERS)

REMOTE SENSING OF ENVIRONMENTAL QUALITY IN RELATION TO LAND MANAGEMENT

Leonard W. Bowden, Ph.D.
Associate Professor of Geography
University of California, Riverside

Remote sensing of the environment, when properly applied, is a technique to monitor environmental quality. The phenomena sensed is that which influences quality and includes numerous things that man can experience. Many of the phenomena in mans experience are unlikely to be subject to remote sensing, but they cannot be ignored. In other words, a system of remotely sensed indices of environmental quality may be developed and used effectively to inform but should not be used to dominate policy.

In a like manner, we have been negligent in failing to fully use remote sensing techniques as a means to aid future land management. All too often, detection of effluents, evaluation of already blighted areas or spot checking of conditions is as far as remote sensing gets used. Unfortunately, newly formed political and popular fronts for the assessment and improvement of environmental quality run the risk of using ill-informed and ill-considered popular action that will alleviate some problems detected by remote sensing and aggravate other, more serious problems.

It seems clear that no policy regarding environmental quality, whether remote sensing is involved or not, could be meaningful if it took less than a regional perspective or outlook and often a world-wide view is desirable. It also seems clear that when dealing with land use and/or land management, anything less than predictive models for future use and preventive models for future quality deterioration are necessary.

Land does not exist in any definable "pure" form--geologically or ecologically--and land pollution means departure from a normal rather than departure from a pure state. Because the land is both diverse and subject to natural or cultural change, the key problem is to determine if the changes are within a broad "normal" range or if they are degradative. And, can degradation be identified, classified and judged? Is it harmful to man and nature?

A land environment is always subject to pollution be it volcanic dust, deer manure or disposed beer cans. Most pollutants are soon broken down or integrated into the environment through decay, burial, settlement and so forth. Over the eons, absorption, oxygenation, and consumption easily clear and disperse small amounts of pollutants. Interaction in the environment among land, air, water and biomass tends to stabilize or control excessive pollution. Except in geologic time spans, little alteration occurs on the natural landscape. However, man has recently upset the cycles of erosion, deposition, decay and regrowth by impressing on the total environment a new and demanding cultural landscape.

Cultural or human pollution of the land has expanded exponentially in the last two centuries. Streams have become sewers unable to dispose or control the material dumped into them. Rural areas are collectors of discarded junk and urban cities are ribbons of refuge and garbage surrounding dismal housing and uncontrolled development. At the same time, water and air have also been polluted and ecological systems disturbed and interrupted. The magnitude and intensity of the problems have become so much greater in recent years that they have blossomed into major political issues. The problems have also generated conflicts penetrating all segments of the economic system.

At the present time, limited government action is the rule to be followed. Standards are to be set, action ordered and so forth by various local, national or international governmental agencies. There are very few guidelines for either the private citizen or private industry to follow to be a lesser land polluter. The concept that the only social responsibility of business is to use resources and engage in activities designed to increase profits so long as the business stays within the rules of the game (Friedman, 1962) places the burden on government to set the rules.

However, damage to the land arises from so many sources that only intense cooperation by private and public factions can produce the slightest positive result. And then the index we use to measure the results may also be misleading.

The most widely used index is the Gross National Product (GNP) which represents the goods and services produced in a given period and moving through market channels. As the name implies, GNP is "gross" because it disregards the conventional kind of depreciation, the wearing out of plants and equipment, etc. However, tax deductions are allowed for depreciation to business for such declines. Yet, nobody depreciates the land, allows for wear out or pollution in any form. The GNP does not take account of depreciation of environmental quality. In fact, increase in GNP is often at the demise of resources. If pollution, for example, eroded rather than bolstered the GNP, government agencies and private industry may well have cleaned up the environment years ago (Janssen, 1970).

Unfortunately, so much of our pollution is unmeasurable in money terms such as effect on GNP. How does one value a beer can on the landscape when the production and consumption of the beer and container added to the gross national wealth. Somehow a change in indices is necessary before individuals or agencies can take action to remove or retard pollution. One may detect a sugar beet field full of salinity, but to advise the farmer on action or guidelines to remove or reduce salinity is a different situation, especially if it lowers his annual income.

In the less clearly defined realm of culturally altered landscapes our mobile population is capable of spoiling one region after another. Except possibly in Alaska, so little "wilderness" remains that, even if it all were preserved, it cannot serve a population that seeks it out as a relief from its culturally blighted landscapes of normal residence. The potential for degradation of the quality of living is all around us. First noted in the deteriorating environments of the urban scene, it is now prevalent in all parts of western societies' landscape (Aschmann, 1971).

Within the capability of remote sensing lies three critical and applicable possibilities as summarized from Aschmann (op. cit.).

1. The capability to inventory our entire national territory in terms of environmental characteristics that affect the quality of human living.

2. Early detection of slight but progressive environmental changes.

3. The identification of patterns and associations of variable and disparate environmental features, both natural and cultural, that society can associate with desirable or undesirable environments.

The first of the three above is most critical. The least elastic of the nations (and the worlds) resources is land and land space. Space on, above or below the urban concentrations is of greatest value yet the non-urban space remains critical to our natural resources but is being progressively pre-empted.

It seems worthwhile to inventory in some detail the spaces in and around urban population concentrations to determine what fractions remain and in what land use. How much of the nation's land is in "single-purpose pre-emptive land use?" What are the evolving patterns?

Urban and regional planners need to recognize the ways urbanized landscapes evolve. They make few land use maps, owing to their cost by traditional field survey methods, and, as a consequence a map's utility is limited to a historical or illustrative value and its major value, when used synoptically to observe economic patterns rearranging themselves, is lost. The application of remotely sensed data can help change the situation. Urban fringe problems are widely recognized: (1) disparate land usage and the gross inefficiency of any distribution system that services disconnected development whose conversion is not phased incrementally, (2) from an agricultural investment view, blighted landscapes have social cost in the loss of interim use returns due to "clouded" planning futures and the disinvestment strategies it prompts, (3) agricultural produce also incurs a higher transportation cost. While a policy regulating rural-urban land use conversion in increments of growth is lacking in the United States, a synoptic method comparing a series of photographs can point out where land owners may initiate a conversion long before the necessary formal procedures are begun. Planners or policy makers may take action when they observe agricultural patterns entering an urban-trasition process. By remotely observing tangible land use evidence of decision-making, the synoptic, photographic interpretation urban growth theory (land economics and locational theory) greatly facilitate the planning of the urban fringe (Goehring, 1971).

Evolving land use and management change can be detected early with the use of synoptic remotely sensed imagery. Goehring (1971) found evidence that urban land use successions can be predicted several years ahead of their actual development. Urban and regional planners can foresee transition problems and where they occur, while they develop. Whether they can or will do anything about the problems depends on policy.

Basically, detection of environmental quality should mean early detection of indices or surrogates so that action can be taken. When blighted districts are fully developed they are easily identified visually by almost any observer. We need to recognize earlier the signatures of blight or declining environmental quality. We need to recognize those combinations of physical landscape and cultural management that are associated with and precede blight.

During the 1960's, we established that impoverished rural environments, urban housing quality, land deterioration and classes of socioeconomic conditions were definable from remote sensing methods. All of our research efforts, mostly in Chicago, Asheville Basin, and southern California were checking the system to see if we could compete with ground based observers in doing land use, land and housing quality, inventory and evaluation of existing land resources. Now it is time we used our capabilities to project the future of land use and guide land management in a meaningful way to protect environmental quality.

However, one proceeds with the above if he knows, or thinks he knows, what is a desirable environmental quality. It seems that man needs, in addition to food, clothing and shelter, numerous other items to be satisfied. The most important is diversity. A monoculture or monolandscape seem to be unattractive, whether they are continuous, similar suburban homes or flat, horizon seeking grain fields. Yet, there is no extensive documentation on such important indices as (1) change, (2) boundary, or (3) individualism. Nor is there historical documentation of the relation of the above three to attitudes or environmental quality. Mullens, working with imagery of Los Angeles, found he could class urban housing quality in relation to middle class income by examining three factors--vegetation, litter and open space.

In a like manner, hazards to living (earthquake, fire, flood, tidal wave, landslide, etc.) are identifiable in a regional and often local sense. All of these are predictive, not after the fact. They are not monitoring of past events that deteriorate man's happiness but are projections of where the deterioration can come from. Of course, such items as housing density, industrial location, and recreation area use are well within the realm of being remotely sensed.

In the 1970's, those of us who have looked at remote sensing applications for a long time, are starting to realize some of the actual potential. An example might be the determination of environmental land quality prior to the invasion of an interstate highway plus the prediction of what it will do--not just locally but regionally and nationally. Aschmann states that the concept of the "right and wrong side of the track" has been with us for a long time. But remote sensing should be able to furnish us the data to foresee an area that will become the "wrong side of the track" when and if certain phenomena occurs.

Of course, information taken from remotely sensed data is only useful as a surrogate of what the real scene is. As is the case where both privacy and social contacts are sought on alternate basis. Crowdedness, or the lack of it, of things on the land is most certainly detectable by remote sensing. What is not distinguishable is the desire for privacy or social contact. However, as one builds the totality of environment from those data bits of remote sensing, often a picture or some insight is formed. Land use, transportation facilities, energy supplies, recreation opportunities, or more simply "the role of man's activities on the land" are readily subjected to analysis with remote sensing methodology.

Occasionally, there are surprises such as finding out that urban vegetative condition sensed with color infrared photography is directly correlated with quality of housing and neighborhood income. On the other hand, some apparent sensors are not as useful as the engineering might lead you to believe. Thermal infrared scanners at one time seem to be a potential tool for night-time traffic monitoring but as yet have failed to make the step.

There has been too much publicity on how remote monitors can detect crop vigor, thermal outflows, stream effluents, forest fires and others. It is time we brought the need for land use planning, prediction of land and environmental quality and the capabilities of remote sensing together. In a nation that has the technology and hardware to sense every acre of land but no regional, state or national land use policy, the time for both is overdue.

There is no question that remote sensings greatest contribution is in the detection and inventory of land use. No other method of survey or analysis comes near to remote sensing when land use data is desired. As has been stressed earlier, once the land use is known, then the real or potential "land pollution" can be described. Just as important is that land use is a prime key to existing and potential air and water pollution.

Overall, the "state-of-art" of remote sensing is technically advanced to the point of being very useful for detection of land pollution. The major drawback is "what" to detect and "how will it effect policy?" In effect, before any evaluation as to "benefit-cost" can be made, costs that have previously been part of the social or cultural pollution of production must be subtracted. As a result, standard economic series such as GNP will have a rather bleak look for a long time. If pollution control efforts should expand significantly, new guidelines will be needed to interpret what the statistical series are telling us and what the remotely sensed data are telling us about economy and environment.

Once the policy changes are made, the new data will not be comparable to data in use today. As a result, remote sensing of the environment will play a much more significant role in early detection of pollutants and serve as a method of monitoring policy and regulation enforcement.

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PART II

D. Program Papers (6)

ANALYTICAL PROBLEMS IN AIR POLLUTION CONTROL

A. P. Altshuller
Research and Monitoring Office
Environmental Protection Agency
National Environmental Research Center
Research Triangle Park, North Carolina

INTRODUCTION

A small program concerned with development of new or improved techniques for measuring air pollution has existed for quite some time, but particularly from the inception of Federal activities in 1955. Until 1967, this program was primarily concerned with support of research and monitoring needs.

Between 1955 and 1967, a large number of laboratory analytical techniques were developed for air pollutants. Considerable research was done on development of colorimetric and chromatographic techniques. These techniques were applied to air quality measurement and to motor vehicle emissions research. During this period a small number of air quality instruments, particularly those for oxidants and hydrocarbons, were evaluated and improved. Most of the colorimetric procedures used in air quality instruments were developed or improved during this period.

By the mid 1960's, it was apparent that new techniques and sensors were becoming available. Gas chromotographic techniques were well enough developed to justify their use in monitoring instrumentation, but the necessary resources were not available. The costs involved in incorporating a laboratory technique into an effective monitoring instrument for routine general use are considerable.

The Clean Air Act, as amended in 1967, referred to instrumentation requirements in two sections. Section 104 states: "The Administrator may conduct and accelerate R/D of low cost instrumentation techniques to facilitate determination of quantity and quality of air pollution emissions, including, but not limited to, automotive emissions". In

Section 133, annual reports to Congress are required, including a report of progress on "The development of quantitative and qualitative instrumentation to monitor emissions and air quality". These passages in the Act stimulated for the first time the allocation of resources for instrumentation R&D. The pace of these activities has accelerated slowly but significantly since the passage of these 1967 Amendments.

It was clear by 1967 that most of the instruments available for measurement of air quality were deficient in sensitivity, specificity, or ease of operation and maintenance. Emphasis was placed on the development of a new generation of instruments using physical principles rather than wet chemistry. Many of these instruments can be used, with some modification, for monitoring emissions from motor vehicles and from stationary sources.

The 1970 Clean Air Act also involves additional measurement capability for mobile emission sources. The development of new power sources or propulsion systems requires that we have analytical procedures capable of qualitatively and quantitatively measuring pollutants "which cause of contributes, or are likely to cause or contribute to, air pollution which endangers the public health or welfare but for which standards have not been prescribed" in accordance with Section 202 of the 1970 Clean Air Act. In general, Section 202 requires that measurement techniques be prescribed for any air pollutant, for which standards are promulgated, that is emitted from motor vehicles.

Evaluation of instrumentation for measuring emissions from stationary sources has recently been initiated in accordance with provisions of the 1970 Clean Air Act. Section 110 (2 F), on Implementation Plans, states that approval of such plans shall include, among other aspects, "requirements for installation of equipment by owner or operators of stationary sources to monitor emissions". Section 144, on inspection, monitoring, and entry, states: "The Administrator may require the owner or operator in carrying out provisions of Section 110, 111, and 303 to (C) install, use and maintain monitoring equipment or methods; (D) sample such emissions (in accordance with such methods, of such locations, at such interests, and in such manner as the Administrator shall prescribe." These provisions certainly will require the acceleration of both R&D and the evaluation and standardization of instrumentation and of sampling and analysis procedures for emissions from stationary sources.

A list of important areas of need for air pollution measurement capability are listed in Table 1. The listing is divided among air quality, motor vehicle emission, and stationary source requirements. The order within each area proceeds from research on pollutant composition and concentration, as related to atmospheric characteristics and biological effects, to regulatory needs. Most of the techniques presently available resulted from earlier R&D programs of air quality surveillance activities. However, the Environmental Protection Agency will soon outrun this reservoir of measurement capability when it begins impending regulatory programs. It is essential that measuring requirements for R&D projects be supported now, or the measuring techniques will not be available for regulatory requirements later. The complexity of the process and the timing involved will be considered in greater detail later in this discussion.

Important criteria for air quality instrumentation are listed in Table II. Of course, these same criteria apply to many other instruments. Sensitivity requirements can vary greatly. For monitoring air pollution, the ability to measure 10 to 1000 up/meter. It appears that at stationary source applications the concentration range will be 100 to 1000 times higher. It follows that an instrument may have more than satisfactory sensitivity for monitoring stationary source emissions, but totally inadequate sensitivity for measuring ambient air quality. Response times of 1 second or less are needed for some motor vehicle applications, whereas periodic analyses once every 5 or 10 minutes, or even less frequently, are required for other air pollution measurements. Fortunately, it is possible to develop instruments with appropriate characteristics for the entire range of applications.

A reasonable position is to develop the minimum set of different instruments. Such an approach will tend to minimize instrument development costs, reduce problems of reliable commercialization of instrumentation, and speed standardization and collaborative testing programs. This approach must also produce instruments adequate for each of the applications listed in Table I at a reasonable cost per instrument.

A sequence of activities required to develop and commercialize an instrument is given in Figure I. In many past and some present instrument projects, a pronounced tendency to bypass a number of steps in the given process had prevailed. The net result has been either unusable instruments or expenditure of much work in rebuilding instruments. Aside from the cost and inefficiency involved in them, such abbreviated approaches actually prove more time-consuming than an approach that systematically follows through on the necessary steps as listed. As indicated in the time scale, it is most unusual for this sequence to take less than 2 to $2\frac{1}{4}$ years; the sequence can require more than 3 years if research problems occur early in the process or if prototypes must be redesigned.

The substantial period of time indicated here as essential for development of a satisfactory instrument reemphasizes the need to anticipate instrument requirements very much in advance of regulatory deadlines. Unless they are developed for R&D projects, prototype instruments will not be available when required for regulatory standards. Cumbersome and often inadequate manual analytical methods must be substituted, to the discomfort of all, while the overdue instrumentation is being developed.

AIR QUALITY MEASUREMENTS

Instrumentation for Measuring Atmospheric Gases and Vapors

This discussion will be concerned primarily with the present status of and anticipated needs for instruments that can monitor ambient air. Point sampling instrumentation, along with remote and long-path-type instrumentation, will be considered for the monitoring of gases. Ambient air monitoring needs will be considered to include not only determination of urban pollution, but measurement of pollution on a regional and global scale. Because a number of atmospheric substances of concern are not primary emissions from chemical reactions, atmospheric transformations must be considered.

Methods of analysis and instrumentation available up to about 1966 have received detailed consideration in a number of reviews (1-7). Therefore, this presentation will emphasize advances in the last several years. Our first concern is with the justification for the development of new or improved instrumentation. It will be necessary to consider the deficiencies of instruments that have been available until recently to analyze ambient air.

Almost all of the air-monitoring instruments installed up to 1970 were based on analytical approaches developed 10 to 15 years earlier. Many of the individual types of instruments are cumbersome, of low specificity, of limited sensitivity, and difficult to maintain because of complexities of design. Some of the instruments suffer from only one or two deficiencies, while others fail in almost all aspects. As a result, the amount of valid measurement data obtained has frequently been limited.

Attempts were made to improve some of these instruments with respect to specificity of response for ozone (8) and hydrocarbons (9,10). Such activities were viewed as temporary expedients necessary because of the lack of funds to develop new instruments. The approach usually taken was to utilize a substrate in the inlet system of the instrument which would remove or hold back interfering substances. Experience has shown that such systems do not work very effectively in routine monitoring operations, although they can be handled successfully by R&D personnel in field studies. No R&D activity can anticipate all of the problems associated with operations under a variety of routine conditions in the field. Variability in time to partial or complete breakthrough of the interferences through the substrate under varying atmospheric conditions is one of the problems often experienced. In general, instruments that require use of auxiliary clean-up systems to achieve specificity are more prone to give incorrect results than instruments whose basic sensing principles confer the required specificity.

A number of instruments have been in common use in monitoring networks during the past 10 to 15 years. When these instruments are considered in terms of sensitivity, specificity of response, simplicity of response, simplicity of construction and operation, or reliability and reproducibility of operation, they have proved inadequate, usually with respect to several of these criteria. As a result, few concerned persons have expressed satisfaction with instruments available during the last 10 or 15 years in monitoring networks. Unfortunately, little incentive and fewer resources were available to remedy the situation until recently.

Although the resources available in the last several years have been modest, considerable progress has been made, particularly with respect to new or improved instruments for measuring inorganic gases. Instruments have been developed which are now receiving or have received field evaluation for sulfur oxides, ozone, carbon monoxide, nitric oxide, and nitrogen dioxide. In addition, a better technique for determination of non-methane hydrocarbon has been developed. Most of these instrument developments have utilized sensors or laboratory equipment produced by research in recent years. However, a considerable range of activities has been required to convert these into usable air pollution monitoring instruments. Sensors had to be evaluated with respect to sensitivity and specificity for urban air pollution requirements. Long-term stability and reproducibility or operation had to be evaluated. Breadboard laboratory equipment had to be packaged as field instruments. Field studies have been required to permit comparisons of instruments used for each of the several pollutants under representative ambient air conditions. Such investigations, from laboratory evaluation of the potential for applicability of a sensor to air pollution needs through field evaluation, require several years of continuing efforts. Field evaluations indicate that all of these instruments have the sensitivity and specificity needed for urban air pollution applications. The instruments also should be capable for measuring so-called near-urban pollution.

The gas chromatographic technique for carbon monoxide and methane utilized in former years in laboratory photochemical studies (11-13) was developed into a convenient monitoring instrument (14, 15). In combination with a capability for measuring total hydrocarbons, such a gas chromatographic analyzer provides a highly specific and sensitive means of analyzing carbon monoxide and non-methane hydrocarbons over a wide range of atmospheric concentrations. As a carbon monoxide analyzer, the gas chromatograph is much more sensitive and specific than current non-dispersive carbon monoxide analyzers. This approach can also be extended to include monitoring for other gaseous hydrocarbons. The direct analysis for methane is much more desirable than the earlier attempt to use substrates to remove hydrocarbons other than methane (9, 100. This type of technique has given erratic results in routine monitoring activities because of the care necessary to maintain the characteristics of the substrate utilized to provide the specificity required. Another technique developed for methane and other hydrocarbons involves selective combustion, with subsequent detection by a water sorption sensor (16).

The present oxidant analyzers are unsatisfactory monitoring tools. The "oxidant" has no exact meaning since the response obtained depends on the presence of various interfering substances. The substrate used to eliminate sulfur dioxide interference oxidizes nitric oxide to nitrogen dioxide and thus increases the signal caused by nitrogen dioxide (8). Recently, it has been shown that hydrogen peroxide is an atmospheric oxidant, but the response of commercial analyzers to this oxidant is poor (17). It should be evident that each of the major oxidants should be measured separately. Several ozone analyzers have been developed and evaluated under field conditions. All of these instruments are based on utilization of chemiluminescent reactions (18). The three types of reactions involved are as follows: (1) reaction of ozone with Rhodamine B absorbed on silica-gel disc (Regener Method), with emission at 0.59 micron; (2) mixing of ozone with excess nitric oxide, resulting in chemiluminescence from excited nitrogen dioxide that extends from 0.6 to 3.0 microns; and (3) mixing of ozone with excess ethylene, resulting in a chemiluminescence peak near 0.43 micron (Nederbragt's Method). All of these systems provide a specific and sensitive means of analyzing ozone rapidly over an adequate linear range. However, both the Regener (19, 20, 21) and the ozone-nitric oxide techniques (18, 22) have several disadvantages, compared to the Nederbragt technique, for use in a routine air monitoring instrument (18, 23, 24).

The Regener approach requires preparation and calibration of the disc. Because of the activation and decay characteristics of the chemiluminescent surface of the disc, a 4-minute mode of operation is preferable; the mode involves a calibration cycle, purge cycle, sample sycle, and purge cycle (20, 21). This type of operation also complicates methods for obtaining signal read-out. The ozone-nitric oxide reaction requires use of reduced pressure to avoid quenching the chemiluminescent reaction (18, 22). Detection of emissions in the spectral region involved dictates the use of photomultipliers near the edge of the chemiluminescent response above 0.6 microns; thus cooling to -20°C is required to obtain a sensitivity down to 0.01 ppm. The Nederbragt-type detector can operate at atmospheric pressure without quenching and with a sensitivity down to 0.003 ppm at 5°C with a less expensive photomultiplier (18, 23, 24). The ozone-ethylene reaction can be used with a detector of less complicated design, excellent operation, and the good cost and size characteristics.

The flame photometric detector has received considerable attention in our program for measurement of sulfur dioxide, hydrogen sulfide, and other sulfur compounds (14, 25, 26). This technique involves a response to both inorganic and organic sulfur compounds because these substances form S_2 species in the flame zone which are responsible for the emission observed. Several field evaluation studies already completed have demonstrated the effectiveness of this sensor, both as a sulfur analyzer and as a detector in a monitoring gas chromatograph (26). This approach is more attractive than most of the other techniques available for measuring sulfur compounds. The flame photometric sensor has the following characteristics: (1) high specificity for sulfur compounds if emission is measured between 0.39 and 0.40 micron; (2) high sensitivity (0.005 ppm); (3) linear response in ambient air concentration range; (4) fast response characteristics; (5) and a gas flow system (no liquid reagents). The flame photometric sulfur detector is also the only detector sensitive to sulfur compounds that can be used practicably in a gas chromatographic analyzer. When sulfur dioxide is the predominant sulfur species present, the flame photometric analyzer can be used as essentially a sulfur dioxide monitor. The gas chromatographic analyzer has been used as a specific and sensitive measuring instrument for sulfur dioxide, hydrogen sulfude, and methy mercaptan (26). The gas chromatographic system has been readily modified to measure a wider variety of organic sulfur compounds where appropriate, such as in the vicinity of kraft paper mills (27).

Several varieties of electrochemical or electroanalytical techniques have been utilized in sulfur oxide monitors (28). Research and development continues on these approaches. Electroanalytical techniques are rarely specific. Liquid or solid substrates are often used to confer specificity. One type of electrochemical transducer utilizes a selective membrane along with a galvanic cell having an electrode potential selected to reduce interferences. Work has been done on selection of electrode and electrolyte materials and membranes for development of sulfur dioxide and mitrogen oxide analyzers (29). This sulfur dioxide analyzer is a compact, relatively low-cost instrument. Its sensitivity at present is adequate for short-term emission measurements but is marginal for continuous measurement of sulfur dioxide. The sensor utilizes 1.)N H_3SO_4 electrolyte, a gold sensing electrode and a lead dioxide counter-electrode with a 1-mil polyethylene membrane. With potentiometric control, interference from nitric oxide is low, but hydrogen sulfide constitutes a significant interference. Response time is less than a minute. This analyzer requires improvement for use in ambient air analysis. Because of its mode of operation, simplicity of construction, compactness, and low cost, it offers possibilities for use in large monitoring networks for measurements averaged over extended time intervals, such as 24-hour periods.

Measurement of nitric oxide in the ambient atmosphere has involved use of analyzers utilizing the colorimetric Griess-Ilosvay reaction for nitrogen dioxide (9), in which the nitric oxide is oxidized to nitrogen dioxide before analysis. A number of efforts have been made to overcome difficulties in developing an oxidizing substrate capable of providing high conversion efficiencies over a range of atmospheric conditions. The stoichiometry of the colorimetric nitrogen dioxide reaction used has been in dispute (30). In addition, the nitric oxide and nitrogen dioxide colorimetric analyzers have been difficult to keep in proper operation. No electroanalytical or ultraviolet analyzer has yet been provided that is adequate for ambient air monitoring of nitrogen oxides. The need for improved instrumentation is particularly urgent for nitrogen dioxide.

At present the most promising approach involves the use of chemiluminescent emissions from the lectronic transition, NO_2 - NO_2, produced in the reaction of nitric oxide with ozone (22). The emission spectrum extends from 0.6 to 3 microns, with maximum intensity near 1.2 microns. This method for nitric oxide by determination is linear from 0.004 ppm up to 10,000 ppm. Photomultipliers responding from the outset of emission at 0.6 micron to their cutoffs at 0.8 to 0.9 micron have been evaluated. To obtain a sensitivity down to 0.004 ppm, choice of photomultipliers must be optimized and the operating temperature of the photomultiplier reduced to -20°C. Since such sensitivity is not needed in measurement of source emissions, less sensitive photomultipliers operating at room temperature can be used. For a wide range of gases present in polluted air, quenching of the chemiluminescent reaction has not been observed at reduced pressures. No interfering species have been identified. This same reaction has been mentioned earlier as one method for ozone measurement.

The reaction of nitric oxide with atomic oxygen produces excited states that emit weakly, with some line structure occurring between 0.35 and 0.45 micron, followed by a more intense unstructured band with a miximum near 0.65 micron (32). Since atomic oxygen reacts with nitrogen dioxide to form nitroc oxide on a one-to-one basis, this reaction can be used to measure $NO + NO_2$. This reaction can be used as the basis of a rapid-response instrument for measuring nitrogen oxides. Use of the emission in the 0.65 micron region only provides discrimination against the chemiluminescent emissions produced by the corresponding reactions of atomic oxygen with carbon monoxide and sulfur dioxide (32).

Instruments have been fabricated for monitoring nitric oxide in ambient air by reaction with O_3, and NO_x by reaction with atomic oxygen (33, 34). Field evaluation of these instruments will follow.

Optical techniques based on absorption of energy by pollutant molecules in the ultraviolet, visible, infrared, or microwave regions have found little application in ambient air monitoring. An exception is the non-dispersive carbon monoxide infrared analyzer. An infrared fluorescent analyzer has been developed for CO that has high sensitivity and specificity (35). Other pollutants existing at lower concentrations do not absorb sufficient energy to permit utilization of other present commercial types of NDIR atmospheric analyzers. Improvements can be achieved by multiplexing (the simultaneous observation of multiple spectral resolution elements), which can be used to obtain higher signal-to-noise ratios (36). Multiplexing can be obtained in a variety of optical devices, including multiple-channel radiometers, interferometers, dispersive matched-filter spectrometers, grating spectrometers, and cross-correlation non-dispersive analyzers (36). More use of this technique has been made in remote-tuned closed-path instrumentation, but multiplexing can be used to advantage in both types of applications.

In recent years, some of these optical techniques have been developed with specific application for ambient air analysis. These approaches involve either differential spectrophotometry or correlation spectroscopy. The technique of correlation spectrometry involves molecular absorption, in which a portion of the ultraviolet or visible spectrum containing vibrational-rotational band spectra is compared with a replica of this spectral region stored within the spectrometer. Point-sampling type correlation spectrometers for SO_2 and NO_2 with an optical path length of 2.5 meters have been fabricated and evaluated in Toronto and Los Angeles (37, 38).

The second-derivative spectrometer electromechanically processes the transmission versus wavelength function to produce a signal that is proportional to the second derivative of this function. This technique results in enhancement of signal-to-noise ratio and improved specificity. A spectrometer of this type has been fabricated to analyze nitric oxide, ozone, sulfur dioxide, and nitrogen dioxide in the 190 to 400 nanometer region (39). Sensitivities ranging from 0.003 ppm for NO and SO_2 to

0.02 ppm for NO_2 are reported for a 1-meter white cell with 20 passes. Both techniques make possible greater specificity by taking advantage of the details of band structure. They also provide somewhat improved sensitivity. However, the electronic and optical systems utilized can be involved and expensive. It is not clear whether these types of optical systems will be competitive in response characteristics, field performance, or cost-size characteristics with the instruments discussed previously for ambient air monitoring.

Another approach is the use of a folded laser beam with white-cell optics. With a laser, a long narrow glass pipe could be used rather than the usual large heavy steel tank (36, 40). To obtain the sensitivities needed for ambient levels of pollutants, at least a 1-km path is needed, requiring a 6-meter base length. Since both an analytical and a reference wavelength are needed, tunable lasers are highly desirable. The tunable semiconductor dioxide lasers, such as the lead-tin-telluride laser now under evaluation, is attractive because of its small size and extremely high resolution that results from continuous tuning over several tenths of a wavenumber around 10 microns (36, 41). Because of its small size, this type of laser plus a detector with excellent sensitivity, such as the mercury-cadmium-telluride detector in a common liquid nitrogen cooler can be used as the key elements in a closed-path optical instrument (36). A spin-flip Raman laser providing tunable infrared radiation has been used to measure nitric oxide in the ppm range (42).

All of the instruments or concepts discussed have involved point sampling; that is, the atmospheric sample is pulled into the instrument through a probe or inlet line of some type. Such types of instruments may or may not integrate over time, depending on response characteristics or deliberate provision for integration of the sample or the signal over time. Integration over space is not involved, except as meteorological conditions influence the flow of pollutants past the sampling site. The measurements obtained are not necessarily representative of pollutant levels over extended areas of the city or over entire air quality regions.

A completely different approach to ambient air analysis involves the use of long-path or remote optical measurements. Such optical instruments would provide the ability to integrate over space in two or in three dimensions.

The Research and Monitoring Office of the Environmental Protection has not only a program for development of point-sampling instrumentation, but also a program for development and evaluation of long-path and remote instrumentation. Correlation spectrometers have been evaluated in several cities for long-path measurement of sulfur dioxide and nitrogen dioxide, using near-ground-level paths with two-ended systems utilizing active sources of energy (38). Path lengths from 100 meters up to 1000 meters were used in these measurements. In the work done in Los Angeles, two path lengths were compared one a cross-freeway path and the other an off-freeway path. Long-path results were compared to point-sampling results, but the experiment also whowed that point sampling could be unrepresentative of the average pollutant concentrations even in a 1000-meter path. These measurements can be limited by aerosol scattering effects or excessive sunlight (38). An open-path circular-filter-type infrared analyzer, programmed for ozone measurement but capable of measuring other pollutants in the 7 to 14 micron range, has been developed (43). This instrument is designed to measure ozone between 0.01 and 1 ppm at path lengths from 400 to 1600 meters. Another investigation being supported is concerned with the potential of a CO_2 laser system for long-path measurement of ambient air pollutant concentrations (44).

The optical instruments discussed thus far involve either two-ended systems, or use of reflectors over fixed path lengths. Ideally, the open-path system of choice might involve a pulsed signal with ranging capability. If such a system could be developed with sufficiently extended range, it could cover much of an urban area in three dimensions. Such a system would probably require a highly developed pulsed laser system with comples data-handling capacity. A lidar-type system of this sort has received some evaluation by several groups for estimating total particulate loadings in the atmosphere (45 - 47). Similar systems do not presently exist for measurement of gaseous pollutant molecules. The use of laser Raman spectroscopy offers possibilities, but sensitivities appear marginal at present (48). Considerable augmentation of the scale of the present efforts will be necessary to develop practical systems for routine monitoring activities.

Still another area of interest involves the use of remote optical instruments mounted in aircraft. The instrumentation can be pointed at the earth's surface to mesure the albedo of the multiple path of sunlight passing through the atmosphere to the surface and reflected upwards to the aircraft-mounted instrument. Correlation spectrometers for sulfur dioxide and nitrogen dioxide have been evaluated in flights over several cities (38). This technique also has applicability to monitoring of stack emissions and plumes (38). However, several problems exist in applying the technique. In a clear atmosphere the equipment tends to operate reasonably well, but scattering by aerosols limits use of the equipment and also renders uncertain the appropriate path length to include in the calculation. In addition, such aircraft measurements are limited by any atmospheric conditions that interfere with flight operations.

If aircraft operation of remote instrumentation is possible, various earth-oriented satellite applications also are possible. Such satellites would not offer the flexibility, accuracy, and general utility of aircraft in taking measurements over urban areas of air quality regions. However, satellites may have eventual utility for measuring long-lived pollutants such as carbon monoxide and submicron particulates on a global scale, although, adequate measuring techniques are still lacking at the present. NASA is supporting effort particularly for methods that analyze carbon monoxide by utilizing both infrared correlation spectroscopy and nondispersive infrared techniques. The latter approach was selected as applicable after a survey on numerous trace gas detection techniques (49). Applications of optical techniques in the upper atmosphere of the earth or to other planetary atmospheres will not be considered in the discussion.

The chemiluminescence ozone, and the gas chromatographic carbon monoxide and methane instruments have already been used in low-concentration-level geophysical measurements (50, 51). The flame photometric sulfur oxide and the chemiluminescence nitrogen oxide monitors may be usable for nonurban or rural measurements, but do not presently have the sensitivity for geophysical measurements. The initial emphasis has been on development of equipment capable of continuously or periodically measuring pollutant concentrations in samples of ambient air collected in a very short time interval. However, for urban measurements as well as nonurban and geophysical studies, integration of concentration over time periods of 1 to 24 hours is an alternative to the conversion of continuous measurements to averaged values for these periods by data reduction techniques. Work is just being initiated on the possibility of utilizing several of the available types of sensors for integrated measurements.

Monitoring capability is especially important for carbon monoxide, sulfur dioxide, hydrocarbons, ozone, and nitrogen dioxide because air quality standards for these widespread pollutants will be established throughout the United States (52). In addition, a number of other gases or vapors are of considerable concern or of potential concern. These substances include hydrogen sulfide, organic sulfur compounds, hydrogen fluoride, hydrochloric acid, chlorine, and nitric acid. With the possible exception of hydrogen fluoride (and water-soluble fluorides) the lack of data makes it difficult to estimate the levels or widespread prevalence of these substances.

As already discussed, a sensitive and specific gas chromatographic technique is now available for hydrogen sulfide and organic sulfur compounds (26, 27). Hydrogen fluoride is generally measured as flouride along with other water soluble fluorides. However, a fully satisfactory monitoring instrument does not appear to be available. The ion-selective fluoride electrode may have the greatest potential because it has been reported to have acceptable selectivity and reproducibility (54). Colorimetric methods utilized have required considerable processing, including distillation, because of poor specificity. The ion-selective electrode has not yet been incorporated into an operational field instrument.

No methods are available that have satisfactory specificity for hydrochloric acid, chlorine, or nitric acid. Hydrogen chloride is emitted from combustion of chlorine-containing coals and incineration of chlorine-containing materials, particularly plastics, and this acid may also be formed by atmospheric photo-oxidation of chlorinated solvents. Therefore, hydrochloric acid may be more prevalent than is often assumed.

Nitric acid is a direct emission product from nitric acid manufacturing, but a much more important source may be photochemical reactions. Very little of the nitric oxide emitted is ever accounted for in the form of particulate nitrate. Nitric acid has been shown to be an important product of photo-oxidation of nitric oxide in the presence of hydrocarbons in laboratory experiments (55). The kinetic mechanisms usually postulated for conversion of nitric oxide and nitrogen dioxide to products also favor nitric acid formation. Because of a lack of an acceptable technique for atmospheric analysis, we cannot assess the importance of nitric acid as an atmospheric pollutant. Optical techniques, including open-path instrumentation, should offer possibilities for measurement of nitric acid, hydrochloric acid, chlorine, and hydrogen fluoride.

Thus far, the discussion has greatly emphasized inorganic pollutants. In part, this reflects the development of air quality criteria for only one group of volatile organic substances - nonmethane hydrocarbons (52). The lack of additional differentiation among volatile organic substances does not result so much from lack of laboratory analytical methods as from lack of routine monitoring techniques.

Gas chromatographs with flame ionization detectors have been utilized in mobile laboratories to analyze atmospheric samples for identification and quantitation of 30 to 60 different aliphatic and aromatic hydrocarbons (56, 57). The chromatographs have been used both for periodic monitoring and for grab sampling. The number of components analyzed has depended on the substrates used and the atmospheric concentration levels. Process-type gas chromatographs for nonmethane hydrocarbons are in development.

Peroxyacetyl nitrate also has been analyzed by gas chromatography with electron-capture detectors (58). Because nitrate is unstable, grab sampling is not satisfactory; however, monitoring on a given site can be conducted. Calibration problems and the lower stability of the electron-capture detector considerably limit the utilization of this technique by monitoring networks. Formaldehyde, acrolein, and aliphatic aldehydes also have been analyzed in atmospheric samples by colorimetric techniques (6). Results reported have involved manual sampling and analysis. Colorimetric analyzers have been fabricated and used in some field applications (59, 60). Unfortunately, these colorimetric analyzers, and other analyzers based on colorimetric techniques, would present considerable problems in large-scale routine monitoring use because of the need for reagent preparation and use of liquid flow systems, and because of varying response to individual aldehydes.

The monitoring that has been done for specific organics has been done by a limited number of groups interested in improving understanding of atmospheric chemistry or in identifying the contribution from various emission sources to hydrocarbon composition. Air quality standards now being established are not likely to require differentiation among these organic species.

Analysis of non-methane hydrocarbons has several fundamental limitations: (1) the measurements cannot be utilized to determine the effectiveness of control, over a given period, of any particular source of organics; (2) response characteristics of the flame ionization detector differ for various hydrocarbons; and (3) the flame ionization detector does not respond to formaldehyde and shows reduced response to other aldehydes.

Even a detailed gas chromatographic analysis for hydrocarbons will not make it possible to follow control of even the major sources of hydrocarbon. This difficulty results from a lack of specific hydrocarbons that can be used as unique tracers of contributions from individual emission sources. However, acetylene and ethylene can be used as indicators of control of combustion sources. In downtown high-traffic-density areas, these hydrocarbons also should serve as indicators of the level of hydrocarbons from vehicular exhaust. Ethylene measurements would be of direct interest in some areas because of its plant-damage characteristics.

Some steps must be taken to optimize flame ionization detector response to minimize deficiencies in response to individual hydrocarbons in atmospheric analysis. Calibration with a single saturated hydrocarbon is the accepted procedure. Such a calibration limits the accuracy of comparative measurements of atmospheres in which the hydrocarbon composition varies.

There is a definite need to include aldehydes in the measurement of volatile organics. Aldehydes can constitute a significant fraction of the reactive organic substances present in atmospheric samples. Better methods for monitoring atmospheric aldehydes are required, however. Optical techniques warrant more consideration for their potential in providing convenient means for monitoring aldehydes in the atmosphere.

Instrumentation for Measuring Atmospheric Particles

Particulate analysis is more complex and in some ways less advanced than analysis of gaseous air pollutants. Certainly, there is a clear lack of instruments for analyzing particulates by mass, size, and chemical composition. The great bulk of available results have been obtained by collecting samples on filters in the field and then weighing and analyzing the collected sample in the laboratory. Particles larger than 10 microns settle readily, and they are usually associated with settled dust and dirt. Particles in this size range are deposited in the nasopharyngeal region of the respiratory tract and do not tend to penetrate effectively into the pulmonary and tracheobronchial regions (61). Consequently, these large particles have not been associated with toxicological action. Particles above 10 microns also do not have significant effects on light scattering and on visibility. Sampling for these large particles has been accomplished with dustfall jars, adhesive coatings, cyclonic collectors (for higher-volume samples), long horizontal tunnels (as fractional elutriators), and various impactors (62). Dustfall jars appear as satisfactory as more complex and expensive techniques are although the dust-fall jar has poor time resolution. The justification for the use of dustfalljars has decreased, however, since they have become increasingly poor measures of particulate pollution as the level of atmospheric particles smaller than 10 microns has increased. In view of these circumstances, little justification exists for directing effort toward development of instruments that can measure particles larger than 10 microns.

Particles between 0.1 and 10 microns probably are those of the greatest concern in air pollution. The particles in this size range contribute most of the particle mass. These particles penetrate into the pulmonary and tracheobronchial regions. The proportion of the particles that are between 0.1 and 1 micron is particularly important.

Particles in this size range are largely responsible for reduction in visibility, and for haze and turbidity. Studies of physiological response to particulate matter indicate that particles smaller than 1 micron can have greater irritant potency than larger particles (43).

Measuring techniques for particles in the 0.1 to 10-micron range have included the Volz sun photometer, the integrating nephelometer, various other forward-scattering and right-angle-scattering instruments, cascade impactors, electron microscopes and tape samplers (62). None of these techniques is adequate for providing a quantitative measurement of mass concentration of 0.1 to 10-micron particulates. Several of these techniques have been research tools not primarily intended to give an overall measure of mass concentration; nonetheless, they have given valuable specialized measurements on particular characteristics of particulates in this size range.

The tape sampler has received considerable use in the measurement of suspended particulates. Visual color of the spots on the tape has been compared with a standard gray scale. More frequently, reflectance or transmittance measurements have been used. Transmittance measurements, however, have been shown to relate poorly to the mass of particulates. Reflectance also is not ordinarily related to total suspended particulate but to "dark suspended matter", inasmuch as reflectance is also a function of absorbance, and absorbance is a function of "color". Both techniques suffer from a number of complications related to variability in the characteristics of the deposits. Neither technique can be considered satisfactory for measurement of absolute concentrations of particulates, but tape samplers can be used to obtain relative values. Careful standardization is critical. Changes in the characteristics of the particulates over periods of years at a site because of fuel changes or control efforts may limit the usefulness of these measurements even for obtaining relative values.

The integrating nephelometer has received considerable evaluation in recent years in an attempt to relate its response to mass concentration of suspended particulates (64-67). This instrument was designed to measure meteorological range, which in turn correlates well with visual range. However, a close correspondence between nephelometer response and mass concentration is obtained only if the particle-size distribution and other particle characteristics remain constant. Unfortunately, the experimental measurements themselves show this not to be the case (68). A visual range of 7.5 miles can be associated with mass concentrations ranging all the way from 50 to 200 ug/m^3. Such a range of mass concentrations represents the entire range of annual geometric mean concentrations of suspended matter in urban areas. Similarly, a visual range of 5 miles can be associated with suspended particulate loadings ranging from 75 ug/m^3 to 300 ug/m^3. Such results clearly indicate that nephelometer measurements are completely inadequate as a means of determing whether particulate emissions comply or tend to comply with air quality standards for particulates. This instrument certainly is useful, however, in its original purpose, which is the measurement of meteorological or visual range. Since light scattering is associated primarily with particles in the 0.1- to 1-micron range, it would seem more useful to attempt to relate nephelometer measurements to mass concentration in the 0.1- to 1-micron range than to total suspended particulates.

The equipment that has received the greatest use in particulate measurement has been the high-volume sampler (62). This device necessitates the replacement of filters that must be transported to the laboratory for weighing and chemical analysis. Ordinarily, a 24-hour-average sample is obtained. When such integrated total weights of suspended particulate measurement has been the high-volume sampler (62). This device necessitates the replacement of filters that must be transported to the laboratory for weights of suspended particulate matter are desired, the high-volume sampler probably is an adequate device. However, this sampler can collect particules well above 10 microns and may not be too efficient in collecting particles approaching 0.1 micron. In addition, the sampling rate is sensitive to the mass of material collected. It is in the utilization of high-volume samples for subsequent chemical analysis that a multitude of problems occur. The glass fiber filter medium as ordinarily used gives high blank readings for a considerable number of cations and anions. Furthermore, reactions can occur on the filter medium between collected materials. Oxidation or volatization of some collected substances can and does occur. Other filter materials can be used, particularly for special analytical applications, but such filter materials usually have limitations associated with their use as well.

It should be apparent that these sampling problems cause greater obstacles to overall analytical techniques themselves. Conversely, it seems futile to expend much effort on improving analytical techniques if the greater source of uncertainty results from the sampling technique itself.

The Anderson sampler has received considerable use as a particle-sizing device. Although materials collected on the various stages must be returned to the laboratory for weighing or analysis, this sampler can serve as a useful interim approach for both mass and composition measurements.

A number of types of instruments ought to be developed for the measurement of particulates. A continuous or periodic monitoring instrument capable of measuring the mass concentration of aerosols below 10 microns is needed. An instrument has been developed that uses an electrostatic precipitator to deposit aerosol particles directly onto a piezoelectric quartz crystal microbalance (72). The balance is sensitive enough to permit measurements of incremental mass for time periods of less than 1 minute. Collection can be significantly influenced by sorption or desorption of water vapor, but this effect can be reduced by use of a dual-crystal detector. Adhesion of larger particles depends on the composition of the particulate and the relative humidity. Addition of a surface active agent to the flow samples can help minimize this difficulty. Because of these possible limitations, such equipment requires careful field evaluation and comparison with normal particle-sizing collection techniques (69-71).

Equipment capable of periodic monitoring of particle-size distribution by mass concentration also is required. An investigation is underway of a new cascade impactor concept for particle-size fractionation, in which by beta-ray attenuation is used to measure material collected on a filter tape.

In view of the difficulties in filter collection and chemical analysis, development of on-site chemical analyzers for various chemical species in particulate matter may be justified. Aside from monitoring needs, improvement of our knowledge of gas aerosol transformation in the ambient atmosphere requires instruments capable of the diurnal monitoring of such species as sulfuric acid, total particulate sulfate, particulate nitrate, and organic aerosol. All of these substances contribute to the loading of particulates in the 0.1 to 1 microns range. Research studies using particle-sizing samplers also have identified lead, sulfate, nitrate, carbon-containing species and ammonium and chloride ions as constituents in the 0.1- to 1-micron range (69-71, 73, 74). To properly associate visibility with air pollution control effectiveness, both the total mass concentration within the 0.1- to 1-micron range and the contribution of these chemical species to the mass concentration must be known. Of course, the direct association with visibility also involves computing the on-site contributions of individual species based not only on mass and size distribution but also on optical characteristics of the particles.

Despite emphasis on automated field methods, laboratory procedures will continue to be useful in particle-size and morphological analysis of airborne particles (75,76). For example, optical and electron microscopy can be used for particle sizing. These techniques, along with x-ray diffraction and other measurements of physical properties, have been used to characterize a wide variety of types of particles. An atlas of photomicrographs of various airborne particles is available to aid in microscopic identification (77).

The electron microprobe has been used for identification and for estimation of relative concentration of a variety of elements including Al, Si, P, S, Cl, K, Ca, V, Fe, Ni, Cu, Zn, Br, La, Ce, and Pb in airborne particles (78-79). In addition, Milliport filters and beryllium disks have been scanned by area for individual elements. Lead has been found associated with bromide and chlorine, but samples also have been scanned in which the lead is present with sulfate. Particles can be located in which no elements can be identified in the X-ray distribution patterns, probably because they contain carbon and other lower-atomic-weight elements.

The monitoring of a variety of hazardous or potentially hazardous elements, including Be, Hq, As, Cd, V, and Mn may require the development on on-site analyzers. For this purpose, X-ray fluorescence techniques should have potential. Work is underway to estimate better the potential of X-ray fluorescence for analysis of airborne particulate fractions. Atomic absorption already has been shown to have potential for continuous analysis of certain elements in air, such as lead (80). Such equipment would allow sampling each 24 hours or oftener, 7 days a week, instead of the more frequent analysis ordinarily associated with filter collections and laboratory analysis. A monitoring technique for various elements also may be desired for analysis of some types of stationary emissions.

Elemental Analysis

Particulate samples are usually analyzed for the elements after collection on a filter. Contamination of the filter media with trace quantities of the elements is a common limitation on analysis. The glass fiber filter most commonly used for collection is not satisfactory for trace analysis for a number of metals because of such contamination. Other substrates, such as polystyrene membrance of Millipore filters, have been used but still are far from completely adequate. For a few elements such as mercury, other collection techniques are used, such as amalgamation or use of gas bullers.

Methods of analysis utilized included colorimetry for a few elements. Usually physical techniques including optical emission spectroscopy, atomic absorption spectrophotometry, neutron activation analysis, X-ray fluorometry, spark-source mass spectroscopy, and stripping voltammetry have been used for elemental analysis. The status of techniques available through 1966 has been reviewed with emphasis on wet chemical techniques, ring over methods and atomic absorption spectrophotometry (81).

Optical emission spectroscopy has been used for elemental analysis over the past 15 years in Federal monitoring activities. This spectrographic technique has been applied to analysis of 16 elements - As, Be, Bi, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Sn, Ti, V, and Zn (82). This method involves considerable analytical skill but it is still only semi-quantitative, lacks sensitivity for a number of elements, and is limited by blanks in the filter substrate.

Atomic absorption is a more quantitative and specific technique and is very sensitive for some elements. This technique can be used for As, Be, Na, K, Ca, Mg, Ba, Cd, V, Co, Cu, Zn, Ag, Ni, and Pb, (70, 83-85). The method is limited by the availability of hollow-cathode lamps. A number of these elements have been measured after particle-sizing of airborne particulates (70). Atmospheric precipitation samples have been analyzed for PB, Zn, Cu, Fe, Mn, and Ni (86).

The thermal neutron-activation analysis of particulate matter in air has received increased use in recent years (87-88). Scintillation counting using a thallium-doped NaI crystal on samples on cellulose fiber as utilized to determine Al, V, Mn, Na, Cl, and Br. In much more ambitious use of neutron activation analysis, airborne particulate samples were collected on polystyrene filters and counted by means of a lithium-doped De detector. The procedure permits determination of up to 33 elements provided that 5-minute irradiations are utilized with 3- and 15-minute cooling periods and 2- to 5-hour irradiation with a 20- to 30-hour radiation (20- to 30-day cooling period (89)). Even with this scheme, most of the low-molecular-weight elements cannot be analyzed. The sensitivities for a number of the elements are marginal or inadequate because of various limitations, including interference of other substances in the sample or a high blank value. Included in the group of elements analyzed by this method are Mg, S, Cl, Ti, Ni, and Ag. Determination of Li, Be, B, C, N, O. F, Si, and P could not be made. Therefore, only a few elements lighter than K could be analyzed. In addition Pb and Cd, biologically important elements that occur in airborne particulate matter, are not included in the scheme. A number of the elements that can be measured are not presently of concern biologically nor do they contribute significantly to the mass of particulates. These elements include Ga, La, Sm, Eu, Au, Sc, Ce, Co, and Th. Elements such as Cr, Fe, Ni, Zn, Se, Sb, and Hg are determinable only after a 20- to 30-day decay period. Therefore, although this neutron-activation analysis scheme in principle appears very attractive, in practice it can only be applied with one or more other analytical techniques if determination of a range of biologically important elements or a mass balance is desired.

A particularly interesting study made recently of elemental analysis of particulates included use of optical emission spectrography parts-source mass spectrography, X-ray fluorescence, atomic absorption, CHN analysis, and chlorine analysis by a colorimetric technique (79). By this means, 77 elements could be determined or estimated in particulates collected in Cincinnati, Denver, St. Louis, Washington, Chicago, and Philadelphia. Bound oxygen could not be included in this analytical scheme. This study is one of the few that permits any evaluation of analytical results from two or more methods on the same samples. The agreement was good between the analyses by atomic absorption and X-ray fluorescence for Ca, Fe, Cu, and Zn, often being within 20 percent or less of each other. The agreement was not as close for K and Pb in some samples. When the analyses for Cu and Zu by optical emission spectrographic technique were compared with those by atomic absorption of X-ray fluorescence, the values obtained by emission spectrography averaged factor of two to three lower. The Fe analyses by the optical emission spectrographic technique also averaged appreciably lower than those by atomic absorption or X-ray fluorescence.

It is likely that even with additional improvements in these techniques, at least two if not three different analytical techniques will be required to cover the range of elements of interest with adequate sensitivity. It also would seem of considerable importance to conduct concurrently some additional comparisons of each of the several techniques for elemental analyses of the same sets of airborne particulate samples. If confidence can be placed in these analyses being correct, on an absolute basis, within 20 to 30 percent, the reliability of each of the methods applicable to each element of interest must be ascertained.

Anion Analysis

Analyses for sulfate and nitrate are routinely made on bulk particulate samples collected on the high-volume sampler at urban and nonurban sites (82, 95, 96). Sulfate is determined by the methylthymnol blue method by means of an autoanalyzer (96). Nitrate is assayed colorimetrically following reduction to nitrite by alkaline hydrazine (96). In investigations on the particle-size distribution of sulfate, several analytical procedures have been used. In one of these investigations, high-temperature reduction of sulfate to hydrogen sulfide was utilized, followed by an iodometric, microcoulometric titration for the hydrogen sulfide (74). In other work (69-97) a modified turbidimetric procedure was used to analyze the size-fractionated material from an Anderson sampler (98). Nitrate was also determined colorimetrically after reduction following particle sizing (71). Phosphate and chloride also have been analyzed colorimetrically after particle sizing (71).

Organic Particulates

A considerable amount of analytical effort has gone into the measurement of various types cf organic substances in particulate matter. Polynuclear aromatic hydrocarbons, particularly benzo (a) pyrene, have received the most attention. Certain of the procedures involving column chromatography followed by spectrophotometric analysis have interference problems associated with them. Paper chromatography, but more usually thin layer chromatography, have received considerable attention as separation techniques. Spectro-polynuclear aromatic hydrocarbons, aza heterocyclics, and polynuclear ring carbonyls after use of column and thin-layer chromatography. Gas chromatography has been applied to n-alkanes in airborne particulates as well as to polynuclear aromatic hydrocarbons. However, adequate separation of benzo (a) pyrene from benzo (e) pyrene and proylene has been a problem in applying gas chromatographic procedures to the analysis of airborne particulates. The details of these developments have been reviewed up to 1968 in several publications (90, 91). The status of work on pesticides, nonvolatile fatty acids and phenols is also considered in one of these reviews (91).

More recently, a simple and rapid procedure has been developed for the determination of benzo (a) pyrene, benz (c) acridines and 7H-benz (de) anthracen-7-one (92). Benzene extracts were separated by one-dimensional thin-layer chromatography followed by analysis of benzo (a) pyrene by spectrophotometry or spectrophotofluoremetry and the benz (c) acridines and 7 H-benz (d) anthracen-7-one in trifluoro-acetic acid, by spectrofluorometry. The procedure was applied to 6-month composites from 52 cities. Most analyses for polycyclic organic materials are applied to 24-hour integrated samples or composites representing even longer integration times. A sensitive procedure, requiring less than 20 minutes, that involves thin-layer chromatography and direct fluorometric measurement was applied to 3-hour sequential air samples for analysis of 7H-benz (de) anthra-can-7-one and phenalen-1-one (93).

Little recent work has been done on pesticides in air. Samples collected at nine urban and rural sites were analyzed for 19 pesticides and their metabolites (94). Chlorinated pesticides were determined on two different gas chromatographic columns utilizing electron-capture detectors, while organophosphate pesticides were determined on two different gas chromatographic columns utilizing flame photometric detectors. Only p, p^1-DDT and 1, p^1-DDT were found at all locations.

STATIONARY SOURCE EMISSION MEASUREMENTS

Source of pollutants among stationary sources very from thermal power plants and incinerators to cement plants and petroleum refineries. Pollutants associated with such sources include particulates, sulfur oxides and nitrogen oxides, but also include fluorides, carbon monoxide, and organics.

Emissions of pollutants from stationary sources may involve flue gases or other vented gases. For some types of extended stationary sources analytical measurements would have to be made by a network of sampling sites or by long-path techniques. Such problems have not received much attention in practice. The present approach appears to be the use of the best available control technology with no continuing attempt after installation to determine compliance in terms of measurement of pollutant concentration.

For flue gases or vented gases up stacks techniques of measurement do exist. In such situations it is important not only to measure the pollutants, but also the gas flow velocity, excess air, moisture, etc. The sampling technique is of great importance and it must be suitable for the specific application. If sampling problems are handled adequately, the analytical measurement requirements can be simplified.

The analytical measurements of pollutants can be accomplished by at least four approaches, (1) intermittant sampling on site with manual analysis in the laboratory, (2) continual instrumental analysis of pollutants collected through probes, (3) in-stack instrumentation, (4) remote instrumental techniques. The second group of instrumental methods would include instruments capable of operating at emission concentration levels and the use of a proper sampling addition interface permitting use of ambient air type instrumentation. The in-stack instruments presumably integrate so that probing the stack configuration is not necessary.

Remote instrumentation cannot be utilized continually, but this class of instrument can be used for rapid surveys and checking compliance. The problem of positioning instruments or probes in stacks is eliminated. Problems associated with the correct relationship between in-stack particle concentration and particle size distribution to that emitted out of the stack into diluation air also are avoided. However, the practical development and utilization of remote optical instruments with the appropriate characteristics is difficult, scientifically and technologically.

Manual Procedures

Methods in common use for measurement of pollutants from stationary sources of emissions have been manual rather than instrumental. Filters, impingers, evacuate flasks and condensation are the collection techniques commonly used. To express pollutant mass loadings and relate results to process variables additional measurements are required. These measurements include stack gas velocity with a pitot tube, moisture in-stack gases determined gravimetrically on condensate, excess air by Orsat analysis and carbon dioxide by the non-dispersive infrared spectrometric method (99-101).

Sulfur dioxide usually is determined by collection of the flue gas in impingers containing hydrogen peroxide (102-105). The sulfur dioxide is oxidized to sulfate and analyzed after reaction with barium chloroanilate colorimetrically at 530 mu in terms of the chloroanilate ion. A second procedure often used involves determination of the sulfate by the barium perchlorate thorium titration method (102, 103). The sulfur trioxide or sulfuric acid mist after separation by filter collection is determined by the same procedures.

Cations such as Al^{+3}, C^{+2}, F^{+3}, Pb^{+}, Cu^{+2}, and Zn^{+2} produce negative interference in the colorimetric procedure by precipitating chloranilate ion from solution. These interferences can be minimized by filtering the flue gas with glass wool at the probe and pretreating the solution with a cation resin. Anions causing interference are not likely to be present in flue gases. The titration with barium perchorate is interfered with by cations such as K^{+}, Na^{+}, NH_4^{+} by reducing the volume of titrant needed. Cationic interferences are minimized by use of a particulate filter in the probe and by percolation of the collected solutions through a cation exchange column. Anions which can co-exist in the collected solutions such as nitrate, chloride and fluoride can interfere also.

These sulfur dioxide analytical procedures have practical ranges from 10 to 3000 ppm by volume. The sensitivities are 10 ppm for 25 to 30 liter samples. The precisions are about ± 3% at 1500 ppm. For sulfur acid aerosol the range is 10 to 300 ppm with a precision at 10 ppm of ± 5%.

Nitrogen oxides often are collected from flue gases in an evacuated flask containing dilute sulfuric acid hydrogen perioxide absorbing solution. The nitric oxide or nitrogen dioxide are oxidized to nitric acid which is measured colorimetrically at 420 mu as nitrophenol disulfonic acid (106). This technique has a range of from 15 to 1500 ppms by volume with a sensitivity of 1.5 ppm. Halogens interfere in this procedure.

In common practice particulates are measured gravimetrically after removal of uncombined water (107-109). The particulate is removed from the flowing gas stream under isokinetic conditions by filtration and condensation. Impinger collection is used as part of this procedure with extract of organic particulate from the impinger solution with chloroform and ethel ether. Aceton washing of the probe and filter holder also is included in the procedure. The total particulate weight of aqueous and organic sample components is obtained by totaling the weights of components. Total sample volume or stack velocity and other parameters are utilized in calculating particulate mass in stack gas.

Continual Instruments for Sampling through Probes

A number of instruments based on optical techniques have potential for use at stack gas pollutant concentration levels. Non-dispersive infrared analyzers or ultraviolet analyzers have been designed for sulfur dioxide, nitrogen dioxide and carbon monoxide. Optical techniques has received attention for visibility of stack gases in plumes. Portable electro-chemical transducers recently developed have potential for use in measurement of sulfur dioxide and nitrogen oxides in stack gases (29). The instruments utilizing the chemiluminescent reaction of ozone with nitric oxide could be utilized for measurement of nitric oxide in stacks (22,31-33).

Gas chromatographic instruments have received considerable evaluation for sulfur dioxide, hydrogen sulfide and organic sulfur gases in Kraft mill effluents (26, 27, 110-112). Gas chromatographic analyzers also could be utilized to measure carbon monoxide and sulfur dioxide in various stack gases.

A source sampling technique for particulate and gaseous fluorides involves use of a heated glass probe to convert hydrogen fluoride to silicon tetrafluoride (113). This type of sampling procedure has been used with a fluoride-selective ion electrode to analyze water-soluble fluorides in stack gases.

An attractive sampling approach would be to convert the stack gases by dilution and cooling to condition approaching these in ambient air analysis. The same instruments could be used as for air quality measurements. This approach would considerably reduce the number of types of instruments in use, calibration requirements and maintenance problems. Studies are needed on the approached sampling interfaces to provide dilution and cooling without changing pollutant composition. Work is in progress on the evaluation of sulfuric oxide and nitrogen oxide analyzers for stack gases.

In-Stack Instrumentation

Instruments capable of operating within the stack itself usually have been based on optical principles. Such equipment must be built to withstand dust, heat, corrosion and vibration. Thermal gradients can cause considerable problems in optical alignments. Calibration of such instruments requires spectra under experimental conditions closely similating stack conditions.

Remote Stack Instrumentation

Remote sensing techniques offer several advantages over the traditional methods of sampling through a probe introduces into a source of emissions. These advantages are as follows: (1) more representative sampling by virtue of spectral integration across the diameter of a stack plume, (2) no need for interfacing between stack and analyzer with probes and sample conditions (3) capability of measuring across an extended source such as an oil refinery.

Electro-optical techniques can be utilized remotely to characterize particulate and gaseous emissions. The use of "Lidar" systems for determining the opacity of plumes from power plants has received considerable attention (114-117). A study of the optical properties of such plumes concluded that the optical transmission of the plume best characterize the aerosol loading in emissions. A "Lidar" system has been fabricated as a research tool for field studies. More practical field equipment will probably utilize the signal backscattered from the plume aerosol rather than the signal backscattered from the ambient air beyond the plume. Such equipment would use a low powered laser. Mass loading measurements of aerosols in plumes also can be made by "Lidar" but interpretation of the signal would require measurements on other characteristics including particle size distribution.

The measurement of gases such as sulfur dioxide can be approached by use of ultraviolet transmission, infrared emission or Raman scattering. Field evaluations have been made utilizing correlation spectroscopy in the ultraviolet (38) and will be made with high resolution infrared emission spectroscopy. Nitric oxide presents a particularly difficult problem because of the overlap of the nitric oxide bands in the 5 u region by water vapor bands.

Raman scattering provides a means of measuring nitric oxide with serious interference by other stack gas constituents. In a preliminary feasibility study insufficient signal to noise ratio was available (118). Improvements in (S/N) can be achieved by use of resonance Raman scatter and by fluorescent scatter techniques.

Detailed analysis of particulates in stationary source emissions for elements or compounds present many of the same problems as those already discussed for atmospheric analysis. Elemental analysis has been limited until the recent increase in concern about trace metals. However, available techniques already discussed for atmospheric particulate samples appear adequate for most stationary source applications. A reasonably extensive sampling and analysis program was conducted some years ago to analyze up to 10 polynuclear aromatic hydrocarbons in samples collected from a variety of combustion processes and industrial processes (119). Analyses were made by ultraviolet-visible spectrophotometry on the benzene soluble fraction of the samples following separations by column chromatography.

MOBILE SOURCE EMISSION MEASUREMENTS

Research measurements of the detailed composition of emissions of motor vehicles have been made for at least 15 years although emission standards for hydrocarbons in blowby gases were not promulgated in California until 1963 and for exhaust hydrocarbons and carbon monoxide in 1966 in California and in 1968 for the U.S. Subsequently, nitrogen oxide standards have been established. Much more restrictive standards for hydrocarbons, carbon monoxide and nitrogen oxides will apply to 1975 and 1976 model year vehicles. Evaporative loss controls also have been established. The limiting factor on implementing standards has not been analytical methods, but control technology applicable to mass production vehicles. The original techniques used for hydrocarbons, carbon monoxide and nitrogen oxides involved use of non-dispersive infrared analyzers. The infrared analyzers for nitrogen oxides have suffered from water vapor interference as well as limitation in sensitivity.

Many techniques have been applied for detailed analysis of hydrogen emissions included mass spectroscopy, dispersive infrared analysis, and by conlometric and colorimetric methods (6). Gas chromotography was applied to automobile emissions shortly after its first use in the U.S. However, thermal conductivity detectors were limited in sensitivity and suffered from water vapor and carbon dioxide interference. Chemical pretreatment to remove interferences and concentration techniques greatly complicated the practical application of gas chromotography to automobile exhaust emissions in the late 1950's. In the early 1960's, the application of flame ionization detectors eliminated these earlier limitations and accelerated the use of gas chromatography to measure the detailed hydrocarbon composition of automotive emissions (120, 121). With gas chromotographic capability well established other analytical methods have not been utilized in recent years. The flame ionization analyzer has replaced the non-dispensive infrared analyzer as the motor vehicle certification technique for hydrocarbons. The non-dispersive infrared technique was of somewhat limited sensitivity for the more restrictive standards and its response was depended on composition in an undesirable manner.

Substructive columns have been used for analysis paraffinic, elefinic, and aromatic hydrocarbons in vehicle emissions using a flame ionization analyzer (122). This technique provides a more rapid approach to class analysis of emission than does gas chromotography.

The use of open-tubular columns combined with solid absorbant or packed columns combined with temperature programming makes it possible to make about any analysis for individual hydrocarbons in emissions desired. Considerable work has been done applying gas chromotographic techniques to organic oxygenates in exhaust. Recently a chemical ionization mass spectrometer has been demonstrated to be capable of measuring a number of aldehydes and ketones in exhaust. Work also has been done on an electrochemical approach to aldehyde analysis, but this technique is not far advanced.

Nitrogen oxide analysis primarily for nitric oxide has been done by several other analytical techniques in addition to the non-dispersive infrared analyzer. These other approaches included use of an oxidizing step prior to colorimetric analysis or use of an ultraviolet analyzer. A mass spectrometric analyzer for nitric oxide also was developed. More recently the need to measure the lower concentrations of nitric oxide required by future standards with use of constant total volume samples has stimulated development of more sensitive analyzers. Electrochemical and particularly chemiluminescent types of analyzers have received recent evaluation.

The chemiluminescent analyzers involving gas titration of nitric oxide with ozone are highly specific, very sensitive and have very rapid response times. A thermal decomposition stage has been used to decompose any nitrogen dioxide to nitric oxide. A closely related technique involves gas titration with atomic oxygen which results in equal responses for nitric oxide and nitrogen dioxide.

The non-dispersive infrared analyzer for carbon monoxide has had adequate sensitivity, specificity and speed of response of vehicle emission applications. Therefore, there has not been much incentive to develop other analyzers. Gas chromotographic analysis for carbon monoxide and the recent fluorescent infrared techniques provide more sensitivity if needed.

All of the instruments or methods discussed previously have been developed either for research, certification or surveillance needs. Inspection of motor vehicles or production line testing requires simple and inexpensive instruments. Some of the instruments discussed are useable for these purposes although more expensive than desired. Catalytic techniques have been shown to have potential. A simple, rapid response optical instrument of moverate cost also has much appeal.

Considerable effort has gone into analysis of oxygenated hydrocarbons particularly aldehydes and ketones. In internal combustion engine exhaust (6, 120, 123, 124), gas chromatographic and colorimetric methods have been emphasized. Phenols also have received attention as products in automobile exhuast (125, 126) by chromatography and colorimetric techniques.

Polynuclear aromatic substances particularly the hydrocarbons have been the subject of several measurement projects on automobile exhaust (91). The work cited on polynuclear aromatic hydrocarbons for stationary sources also included analyses for passenger cars and trucks (119). Recently additional work has been done assiciatin polynuclear aromatic substances and phenols with fuels and fuel additives and engine variables (127). The presence of aza heterocyclic hydrocarbons in automobile exhaust has been demonstrated (128).

Earlier work on particulates in automobile exhaust was concerned with amounts of lead-containing particles (129). During the same period lead was determined polarographically on each of a series of particle sized fractions from the Anderson Sampler, the Goetz spectrometer and other devices from auto exhaust (30). Total particulate and benzene-soluble particulates have been measured in two investigations (131, 132) on exhaust from a number of passenger vehicles and trucks. Auto exhaust particulates after size fraction atom in an Anderson Sampler has been analyzed for lead, nitrate, sulfate and chloride by atomic absorption and by nephelometric or colorimetric procedures for the anions (133).

The ratio of water soluble to water-insoluble lead also were compared. An Anderson sampler as well as a constant volume sampler were used to obtain total particulate and size-fraction atom with analysis for lead, iron and zinc by atomic absorption and bromine by neutron activation (134). Both leaded and non-leaded fuels were utilized. A tunnel type sampling system capable of sampling auto exhaust for particulate matter under realistic operating conditions has been developed (135). This system was utilized with Andersen and Monsanto impactors to do light particle size distributions as a function of vehicle operation conditions and driving history (135). A similar sampling system was used in a more comprehensive study of composition of particulate and gases with fuels with various tetraethyl lead contents (136). Total particulate weight, particle size distribution of particulate, metal analysis on exhaust particulate as well as fuel and engine oil by optical emission spectroscopy, chlorine and bromine by neutron activation, particle chromatomization by electron and light microscopy, and organics by mass spectrometric and ultraviolet fluorescent analysis were the measuring techniques applied to the particulate fraction of the auto exhaust (136).

Diesel exhaust emissions usually are considered of concern because of smoke and odor problems in the vicinity of individual diesel vehicles. Levels of carbon monoxide are very low from diesels (137). Hydrocarbon concentration levels can vary widely (137). Because of the higher molecular weight of diesel fuels the combined emissions of fuel components, low molecular cracked hydrocarbons as well as partial oxygenated organic products presents a substantial analytical problem (120). A portion of these organic components are responsible for the odors associated with diesel exhaust emissions (188-140). Nitrogen oxides also can vary considerably in diesel emissions overlapping the concentration levels produced by vehicles with spark ignition internal combustion engines (137). Polynuclear aromatic hydrocarbons also have been measured at substantial concentration levels in diesel exhaust emissions (141).

Measurement of the concentration levels of a number of components such as carbon monoxide, nitrogen oxides, low molecular weight hydrocarbons and polynuclear aromatic hydrocarbons do not present substantially different analytical requirements from those well established for spark ignition internal combustion engines. Sampling and analysis of fuel hydrocarbons and their partial oxygenated products still present opportunities for analytical activity (120). Although substantial progress has been made in recent years on identification of the odorous components of diesel exhaust much more analytical work is still needed (140).

Considerable use was made in earlier work by Scott research laboratories of dispersive infrared measurements for carbon monoxide, carbon dioxide, nitrogen oxides and some hydrocarbons (138). Non-disperse infrared instruments were used in Bureau of Mines investigations for carbon monoxide and nitric oxide while nitrogen dioxide was measured with a non-dispersive ultraviolet analyzer (137). Colorimetric methods have been used for nitrogen oxides, formaldehyde, aerolan and total aliphatic aldehydes (138). Gas chromotography has been used for analysis of hydrocarbons in combination with column chromotography with identification by mass spectrometry for odor components (140). Considerable progress has been made by this combination of techniques when applied to the oily-kerosine odor fraction and similar techniques are being applied to the smoky-burnt fraction. Column chromotography combined with fluorescence spectroscopy has been used to identify and measure a number of polynuclear aromatic hydrocarbons in diesel exhaust emissions (141).

The use of high molecular weight fuels presents a special problem with respect to the actual form of the higher molecular weight products upon emission. These materials may be present in the atmosphere as vapors, as finely divided organic aerosol or as large droplets that settle to the ground rapidly. Additional investigation is needed to properly define this situation under realistic operating conditions.

While smoke and odor have been the main concern from the standpoint of concern about regulations, other emissions may well have to be included in emission regulations in the future. If emissions from the passenger vehicle equipped with spark ignition internal combustion engines are very effectively controlled by the middle 1970's, the residue contributions from other propulsions systems such as the diesel engine may well become of greater concern.

TABLE I

Air Pollution Program Elements Requiring Instrumentation and Measurements Development, Evaluation, and Standardization

1. Air quality surveillance networks
2. Atmospheric and Plume Research Investigations
3. Biological effects field investigations
4. Air quality standards

5. Motor vehicle emission composition investigations
6. Motor vehicle certification and production line testing
7. Surveillance of production vehicles with mileage accumulation

8. Investigation of stationary source emissions composition
9. Stationary source emission standards
10. Determination of compliance with emission standards

TABLE II

CRITERIA FOR AIR MONITORING INSTRUMENTATION

1. Compatibility with sampling system
2. Sensitivity sufficient to meet monitoring application
3. Specificity of response to pollutant of interest
4. Adequacy of response time for application
5. Simplicity of construction and operation
6. Reliability and reproducibility of operation
7. Compatibility with data handling equipment

STATE OF THE ART IN NOISE MONITORING

Elizabeth Cuadra
Deputy for Program Development
Office of Noise Abatement and Control
Environmental Protection Agency

INTRODUCTION

This paper has been prepared specifically for presentation to an internal EPA working session on environmental monitoring, for the purpose of providing the other attendees with a brief introduction to the state-of-the-art in noise monitoring. Therefore, the depth and degree of detail have been purposely limited in order to provide the breadth of scope appropriate to an introductory paper.

In Environmental Protection Agency usage, the definition of the word "monitoring" is extremely broad, and encompasses such activities as source emission monitoring, monitoring of effects upon receptors, and a variety of other functions in addition to the traditional concept of monitoring the physical or chemical characteristics of the ambient atmosphere or medium. EPA planning appropriate to a national noise abatement program effort would necessarily include significant amounts of effort in these other types of monitoring.

For example, special field studies should be carried out to assess the suspected health effects of extreme community noise environments, to ascertain suitable criteria for noise limitation in outdoor recreational spaces, to determine the actual extent of hearing impairment among the general population, and to determine the typical noise exposures of individuals among the population. However, this paper restricts its attention to only one of the major subdivisions of noise monitoring: the ambient environment itself. Even with this restriction in scope, the present treatment is necessarily superficial and the reader's attention is invited to the list of selected references at the end of this paper, which is provided as an aid to further study.

ELEMENTS OF NOISE ABATEMENT/PREVENTION

Before we consider the details of the monitoring process, it is helpful to consider the elements of any noise abatement or prevention program in terms of a simplified logic model. Figure 1 shows the three basic elements of any noise prevention design problem: the noise source itself, the propagation path between the source and the receiver of the noise (which in most cases are people, and in some cases, may be wildlife or other mixed ecological systems). Any comprehensive prevention or abatement program, to be successful, must consider all three of these elements and their relationships to each other. While real world noise problems are comprised of many sources causing the total noise environment that surrounds each individual receptor, this simplified model provides a useful logic device.

Figure 2 shows the same source-path-receiver model, accompanied by examples of the technical solutions appropriate at each potential intervention point. The role of the receiver in the model is to provide us with the criteria information necessary to establish design limits for the noise environment, which will vary according to the use of the space (e.g., outdoor urban area, outdoor wilderness area, urban residential area, commercial area, etc.). There are two available points of intervention where actions can be taken to prevent noise from reaching the receiver which would be in excess of the established design limits: at the source and in the propagation path.

Intervention at the source, of course, corresponds to providing quieter motorcycles and vacuum cleaners, controlling the extent of the "noise footprint" of an airport, and designing freeways and other ground transportation elements to minimize the extent of their noise impact on the adjacent neighborhoods. Technical interventions in the propagation path include the provision of adequate distance between noise sources and receivers, taking advantage of natural terrain barriers, and the provision of noise resistant barriers (such as shielding walls along highways, building exterior shells designed to insulate against noise for buildings located near noisy airports or freeways, better walls and floor ceiling constructions between dwelling units in multi-family dwellings, and--as a last resort--personal hearing protection for the worker or recreationist in a high noise environment.)

Each of these technical interventions carries with it the necessity of an analogous legal requirement. For example, the achievement of noise reduction at the source corresponds to numerical limitation of source noise emission by regulation, performance standards limiting by regulation the extent of the noise environment permitted by highways and airports, the use of purchasing power and such other motivational means as may be available to government agencies to encourage the design and marketing of quieter noise sources, and the application of consumer preference to motivate the same results. For intervention in the propagation path, the corresponding legal/institutional approaches include the requirement of a noise element in land use plans, the requirement of a quantitative noise prediction in transportation system design, the use of performance zoning in both cities and outdoor recreational areas, the amendment of building codes to establish performance requirements for noise insulation in buildings (especially dwellings); and in the case of the employee work place situation, the implementation of health-related protective laws, of which the Occupational Safety and Health Act (and similar hearing protection regulations within governmental agencies) represent examples.

Much more could be said about the foregoing three-part logic model, in such terms as comprehensive and systematic techniques of achieving a given ambient design goal, and doing so at least total system cost. However, the concept is presented here only for the purpose of providing background to the subject of monitoring noise in the ambient environment.

PURPOSES OF MONITORING THE AMBIENT ENVIRONMENT FOR NOISE

Monitoring of the ambient environment for noise may be desirable for a variety of reasons. No baseline measurement of the typical noise environments in American cities, towns and open spaces presently exists; such a general baseline should be established. A comprehensive monitoring survey is a necessary first step whenever any city undertakes development of a new noise abatement program; the drafting of a performance type noise ordinance specifying a set of ambient limits is a desirable second step. Special projects in baseline monitoring should be undertaken in areas being considered for the siting of new airports, new highways, or other major noise sources as necessary background information for the assessment of environmental impact as a result of the proposed action. Periodic monitoring of the ambient environment for noise should be repeated in outlying areas where fixed permanent monitoring systems may not be justifiable from a cost standpoint; the existence of such monitoring in the past would have saved us from some recently discovered surprises regarding aircraft noise at large distances from airports, for example (in both urban and wilderness areas) which otherwise have to be brought to our attention by complaints of the noise impacted citizenry. Finally, continuous monitoring by fixed monitoring systems should become the rule rather than the exception, particularly for airports, airbases, and highly urbanized areas where knowledge of the time trend of the noise environment can be utilized as a decision-making tool for controlling that environment.

AVAILABLE FOUNDATION FOR A NOISE MONITORING PROGRAM

In the noise pollution field, the state-of-the-art of measurement of the pollutant is well prepared for the job at hand. This is one field where the state-of-the-art of measurement (and, indeed, of potential means for abatement as well) places us in a good position for an action oriented program. The same cannot be said, however, for the state of knowledge on noise effects; the completeness of our knowledge of noise effects is well beyond the general layman's awareness, and yet our ability to predict all the effects is considerably behind our ability to measure the noise itself.

The development of the science of acoustics has been an outgrowth of the sciences of physics and mathematics. Perhaps the most notable early milestone in this development was the major treatise on the theory of sound, written by Lord Rayleigh (in 1872, during his honeymoon on a houseboat trip up the Nile River). A major impetus to the field of noise and vibration as an applied science occurred during the recent development of aviation and space activities, as a result of the need to protect people and vehicular structures from the destructive vibrations which could be induced by intense sound fields from jet and rocket engines. To give an idea of the time scale involved, the

Acoustical Society of America has been in existence for 40 years, the first comprehensive survey of an ambient noise environment with reliable instrumentation was made in 1937, and a major handbook for the use of engineers and other workers in noise measurement and control, "The Handbook of Noise Control" was published in 1957.

Much research has gone into the development of suitable scales for measuring noise in ways that are related to the auditory characteristics of human hearing, and to the subjective judgments of noise environments made by people. Single-event scales have been developed to measure the magnitude of a single noise event (such as the level of noise from a single aircraft flyover or truck passby); and composite scales have been developed for expressing the "noise climate" at a point in a community, taking into account the total noise input from the succession of single events, the duration and frequency of intrusive noise events, and the distribution of such events--during daytime or nighttime hours--around the 24 hour day. Examples of single event type scales are the A-weighted sound level (in dbA) and the Perceived Noise Level (in PNdB). Examples of multiple event (or composite) scales are the Composite Noise Rating (CNR), the Noise Exposure Forecast (NEF), and the Community Noise Equivalent Level (CNEL). Learning the characteristics of scales for expressing noise, together with understanding the circumstances under which each is appropriate, is the first task which confronts the newcomer to the field of noise measurement and control.

The development of acoustics as a science, and its more recent expansion into the field of noise abatement, has been accompanied by the development of a whole system for developing national and international standards for acoustical instrumentation, for the measurement of sound, for measuring the performance of building elements in terms of their noise insulating qualities, and many other special measurements related to the noise abatement problem. Many professional societies and other standards writing bodies have contributed to this effort, notably, the Acoustical Society of America, the Society of Automotive Engineers, and the American Society for Testing Materials.

Institutional arrangements for adoption of acoustical standards include the American National Standards Institute at the national level and the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) internationally. A complete reference listing of such standards writing bodies and standards applicable to various aspects of the noise abatement problem will be available in a forthcoming technical information document to be published by the Office of Noise Abatement and Control, as one of a series of technical information documents supplementing EPA's report to the President and the Congress on noise.

Instrumentation presently available and in use for measuring the ambient noise environment ranges all the way from the simple hand-held sound level meter (which together with its microphone calibrator may cost as little as approximately $500) to a complex, automated, multiple microphone, fixed monitoring network for airports, intended to supply both single event and multiple event information to the airport operator. One example of such a system is the new monitoring system at Los Angeles International Airport, designed and installed at a cost of approximately $200,000.

Between these two extremes, there is a wide range and variety of standardized and commercially available equipment for measuring, recording, analyzing and displaying the characteristics of noise environments. The recent interest in noise as an environmental pollutant, together with the potential market this signifies to instrument manufacturers, has motivated them to begin applying solid state technology, digital techniques, and automatic data analysis systems in many of the recently designed instruments and systems. We can expect to see further payoff in the future in terms of cost reduction, system simplification allowing use by less highly trained personnel, and the availability of more compact and portable equipment.

QUANTITATIVE DESCRIPTION OF A NOISE ENVIRONMENT

Nature of the Acoustic Signal

Suppose we take a simple system consisting of a transducer, an amplifier, and some form of readout such as a level recorder. If we place our microphone at a point in the community so that we can record the time history of the ambient noise environment we may expect to see a rapidly time-varying trace such as that in Figure 3. Figure 3 was obtained from a level recorder trace of the A-weighted sound level over a period of minutes at a point in a typical suburban residential community. The peaks of the spikes give the sound levels of the individual noise events, and the level to which the trace always recedes is the "residual level," formed from the inflow of acoustic energy from many distant sources.

If we were to make an audio recording of the same noise environment, we could then analyze the instantaneous signal at any point in time into its spectrum. For example, Figure 4 shows the typical octave band sound pressure levels we might expect to obtain from the measurement of a passby of a truck or an automobile. Information about the spectral distribution of acoustic energy is usually necessary for design purposes and for purposes of certifying that a particular product meets a noise standard. However, it is not generally necessary (and might be prohibitively expensive) for purposes of routine environmental monitoring.

Referring again to Figure 3, if we were to continue the time trace over a 24-hour period, we would see the results of a large variety of noise producing activities, and the general would decrease during a period at night as the activity level of the community decreases. The amount of this decrease and the time duration of what we may call "night" in terms of quiet varies from one community to another. The point to be made, however, is that a statistical analysis of this time trace would tell us for what percentage of time the noise level exceeds various values. Such a statistical distribution is one way of showing the noise environment at a given point in a community. Figure 5 shows an example of a cumulative statistical distribution in one community, for the 4000 Hertz octave band only. It requires eight such charts to show all the octave bands of interest, for a single community point.

Translation into a Composite Scale

By now, the reader may be experiencing some concern about the number of parameters involved in quantifying a noise environment, and realize the need for simplifying these parameters into a condensed means of expressing the noisiness of a particular location. One step in that simplification is available if the decision can be taken to record the time history in terms of a single event scale which has already applied a particular weighting to the spectrum and therefore expresses the magnitude of each single event in terms of a single number rather than a set of levels in each octave band or third octave band. The A-weighted sound level is a major candidate for such application because it performs well in correlating collections of individual subjective noise judgments against the measured sound levels, and because it is applicable to relatively low-cost monitoring systems.

Even then, we are left with the necessity of expressing the noise environment at the point in terms of a single number which accounts for the time variations involved over the 24-hour period. Attempts to do this in a way that is related to the community annoyance effects of noise have led to a number of composite scales such as CNR, NEF, etc. These composite scales generally take into account such factors as the magnitude of the individual noise events, the number of such events, and the percentage of the events which occur during the nighttime hours when most people want to sleep; some composite scales also account for the duration of the individual events. We believe it is also necessary to account for the existing residual (or background) noise level in the community, and perhaps for such factors as any impulsive noises (such as hammering or riveting) or of the presence of any discrete tones such as caused by a power saw or by fan or compressor noise from an aircraft engine. Although a number of composite scales exist, most of them have been developed to deal with aircraft noise only or traffic noise only, and we are left with the urgent problem of developing a valid universal scale for community noise from all sources which is related in a tested way to the annoyance response of communities of people experiencing that noise environment, in terms of the opinions they express in a social survey.

Once a composite noise scale is adopted, the noise environment at various points in the community (as based on the total experience over any given time period such as a day, a week, or a year) can be quantified, and as a result it is also possible to draw "noise contours". These contours are lines of equal "noisiness" in terms of the selected composite scale, just as contour lines on a topographic map are lines of equal elevation. They can be used to delineate varying degrees of noise exposure on a map, as shown in Figure 6 for a hypothetical airport.

The state-of-the-art in noise prediction is adequate to allow the estimation of sets of noise contours associated with such transportation elements as planned airports, freeways and highways, given as input data the anticipated types, numbers and paths of vehicles involved. The use of quantified noise contour predictions should become a routine part of the process of transportation system planning and design, urban land use planning and design, and the environmental impact statement process as required under the National Environmental Policy Act. Predicted noise contour sets are a crucial tool in the decision making processes associated with the siting and routing of transportation system elements, the appropriate zoning of land uses surrounding airports and adjacent to highways, and the establishment of special building code districts dovetailed into those noise zones.

While noise contours can be predicted adequately for planning purposes, there is no substitute for measurement when one is dealing with a real airport or an existing community, coupled with the vagaries of varying atmospheric conditions, non-ideal flight paths of air vehicles and variable operating modes of surface vehicles. The application of a suitable metric (composite scale) to both the prediction of noise contours and their measurement can provide an invaluable two-pronged tool to control the noise environment.

TYPICAL NOISE MEASUREMENT SYSTEMS

Sound Level Meters

The simplest device for measuring a noise environment is the simple hand-held sound level meter. Figure 7 shows two examples of commercially available sound level meters, capable of providing direct reading meter measurements of A-weighted, B-weighted, or C-weighted sound levels. Figure 8 shows the amount of emphasis given to each part of the audible spectrum by these three standard weighting circuits, together with that given by a D weighting circuit presently under consideration for inclusion in a measurement standard. The A weighting is the most useful, since it approximates the frequency response of the human ear and it has been found to give results that correlate best with individual subjective judgements of noise. The C weighting is useful to have on a sound level meter since it gives a close approximation to the level that would be read with equal emphasis across the spectrum. The effect of applying the A weighting is illustrated in Figure 9, where the actual (unweighted) spectrum of a sample of outdoor residual noise is compared with the spectrum shape that results from applying the A weighting. The performance requirements for the various types of sound level meters, microphones, etc. are prescribed in nationally adopted acoustical standards published by the American National Standards Institute.

Record-and-Analyze Systems

For many purposes it may be desirable to obtain a recording of the noise environment. Such a recording may be played back later as a demonstration of that environment for people involved in the decision making process but who have never experienced the noise environment in question, may be stored for later analysis in the laboratory, and may be subjected to all of the detailed analysis into statistical characteristics and spectral characteristics as outlined above. Figure 10 shows a typical field outfit for obtaining scientific precision audio recordings. It is desirable to have a tape recorder with two channels, since some types of recordings require two simultaneous microphones, and others benefit from having one channel free for a voice narrative by the field investigator. Tape recorders for field use ideally should have a playback capability built in, as it is reassuring to be able to confirm that one has a valid recording before leaving the site.

A variety of analysis and readout alternatives are available when one has the noise history available on an audio recording. For example, Figure 11 shows, in diagram form, the basic equipment for recording and subsequent statistical analysis. When statistical analysis is not necessary, spectral analysis may be desirable, or even a simple level recorder trace as output may be useful for visual display purposes.

Real Time Analysis

For an extensive survey, and particularly when statistical analysis is required, the amount of data can rapidly become excessive in terms of the laboratory analysis time unless real-time analysis is used. The term real-time implies that data processing and display occur almost simultaneously with data input, so that decisions regarding the nature of the input may be made immediately. Figure 12 shows the basic equipment required for real time analysis, with both frequency analysis and statistical analysis outputs shown.

Automatic Monitoring Systems

The need to control the noise environment of airports has given rise to the design and installation of a number of airport monitoring systems. These systems range from simple single event monitors such as those at Kennedy Airport (which measures the Perceived Noise Level of each flight) to the more sophisticated systems which are capable of measuring not only single events but also the "noise climate" (in terms of some composite scale) as experienced at a number of points around the airport. Some of these airport monitoring systems have already proven their usefulness in controlling and reducing airport noise and in providing assurance to those attempting to plan for land use around the airport.

The list of airports in the world which have instituted noise monitoring is a fairly large and rapidly growing one. It presently includes at least the following airports (and even this list may not be complete):

Airports with Noise Monitoring Systems

Amsterdam (Schiphol)
Frankfurt/Main
Stuttgart
Zurich (Kloten)
Paris (Orly)
Osaka
Oslo (Fornebu)
Kennedy, Newark, LaGuardia
Orange County Airport (California)

Other cities which presently have gone out for bids on noise monitoring systems for their airports include Rio de Janeiro, Melbourne (Australia), London (Heathrow) and Tel Aviv. As of this writing there is indication of strong interest by the Boston Port Authority in acquiring a noise monitoring system for Logan Airport, and Los Angeles International Airport's new monitoring system is scheduled to go into operation in December of this year.

The state of California has recently adopted a statewide airport noise regulation, which requires noise monitoring for "noise problem" airports, and sets forth the system specifications for such monitoring systems within the regulation. Figure 13 shows the system diagram for the measurement of a quantity called "hourly noise level," which is a basic ingredient of the calculation of "community noise equivalent level" (CNEL), a composite measure of the "noise climate". The regulation also calls for single-event monitoring. The airport monitoring system voluntarily adopted by Orange County Airport in California was influenced in its design by this airport noise regulation, and the airport monitoring system for Los Angeles International Airport is designed specifically to meet the requirements of the California regulation.

Among the existing airport noise monitoring systems, that at Stuttgart is particularly of interest, partly because the measured noise environment is, in fact, being supplemented by a program of land use control by the government, a necessary complement to the control of the "noise footprint" generated by the airport. Figure 14 shows a layout of the monitoring points around Stuttgart Airport together with a photograph of the central station equipment.

Several airports were noted above which are currently out for bids for new noise monitoring systems. The systems prescribed by these airport authorities have several qualities in common: They all require a number of remote microphone positions, varying from 12 to 16 per airport, with the microphones placed on telephone poles, the measurements made in A-weighted sound level, these levels converted to frequencies proportional to level and then transmitted back to a central station by means of narrow band telephone lines. At that point the systems diverge in their requirements according to the individual needs of the airport. In some cases, only individual events producing levels which exceed a predetermined level are identified. In some, the "noise climate" at each microphone position is computed in terms of some composite scale, usually the noise exposure index Leq, obtained from an integration of the A-weighted sound level from all events, with suitable weighting factors applied to those events which occur at night.

Most of the systems involve a small computer which also includes the flight plan information, and thereby identifies the specific flights which cause preset noise levels to be exceeded. Again, the details of storage and display vary from one airport to another. It is common to have an initial survey done using portable equipment to establish the initial noise contours of the airport environment, and then utilize the fixed monitoring system to prevent the contours from spreading farther. The actual prevention is achieved by the airport proprietor applying his legal prerogatives in allowing or disallowing particular aircraft, pilots or airlines to continue to utilize his airport or to do so under certain specified conditions of takeoff weight, runway utilization, and hours of operation, or such other regulations of the airport as may be necessary to control the noise environment. Even as an information gathering tool, quite aside from any regulatory authority, noise monitoring systems at airports have proven themselves to be extremely effective in curbing the unnecessary or preventable portion of noise associated with airport operations.

In at least one instance, an attempt has been made to apply computer mapping to illustrate the measured noise environment of a portion of a city. Numerous other cities (in other countries) have, of course, performed comprehensive noise mapping surveys using field teams. Figure 15 shows a computer plotted noise map of the measured noise environment of the Mount Royal Plateau, for seven categories of intensity, performed by the city of Montreal as part of its comprehensive noise abatement program. In this instance, the data was obtained by measurements using a portable van, and the computer mapping achieved by off-line treatment of the data. However, this result, coupled with the state-of-the-art in airport noise monitoring, gives promise of the feasibility of automated systems which can measure the noise environment and produce a display of that environment in terms of computer-plotted noise maps.

CONCLUSION

A brief introductory survey has been given of the state-of-the-art in noise monitoring. Selected references for additional study are given in the attached list.

In closing, we should like to emphasize several major points. First, the available technology for measuring noise is ready to support a national noise abatement program. The activities of this country generally lag behind those of other modern industrialized countries in applying this technology.

Second, a key element in the design of automatic monitoring systems applicable to community noise is the development of a universal scale for community noise, simple enough for minimum cost noise monitoring systems, and validated against the subjective judgements of people living with those community noise environments.

Third, there is a broad range of equipment and instrument technology available to apply to the monitoring of ambient noise environments, from the simple hand-held sound level meter to complex, automatic noise monitoring networks. A maximum effectiveness, minimum cost approach to a national noise abatement program will probably require some utilization of both these extremes. For example, maximum flexibility is provided by teams in the field with portable equipment. Recent EPA-funded experiments at Federal City College (Washington, D. C.) have shown that relatively untrained personnel can be trained to make valid noise measurements with simple, commercially available equipment. Long term monitoring of community and airport environments will require the more sophisticated automatic monitoring systems, which afford the most useful information for testing abatement strategies, and for documenting the long term trend in noise environments.

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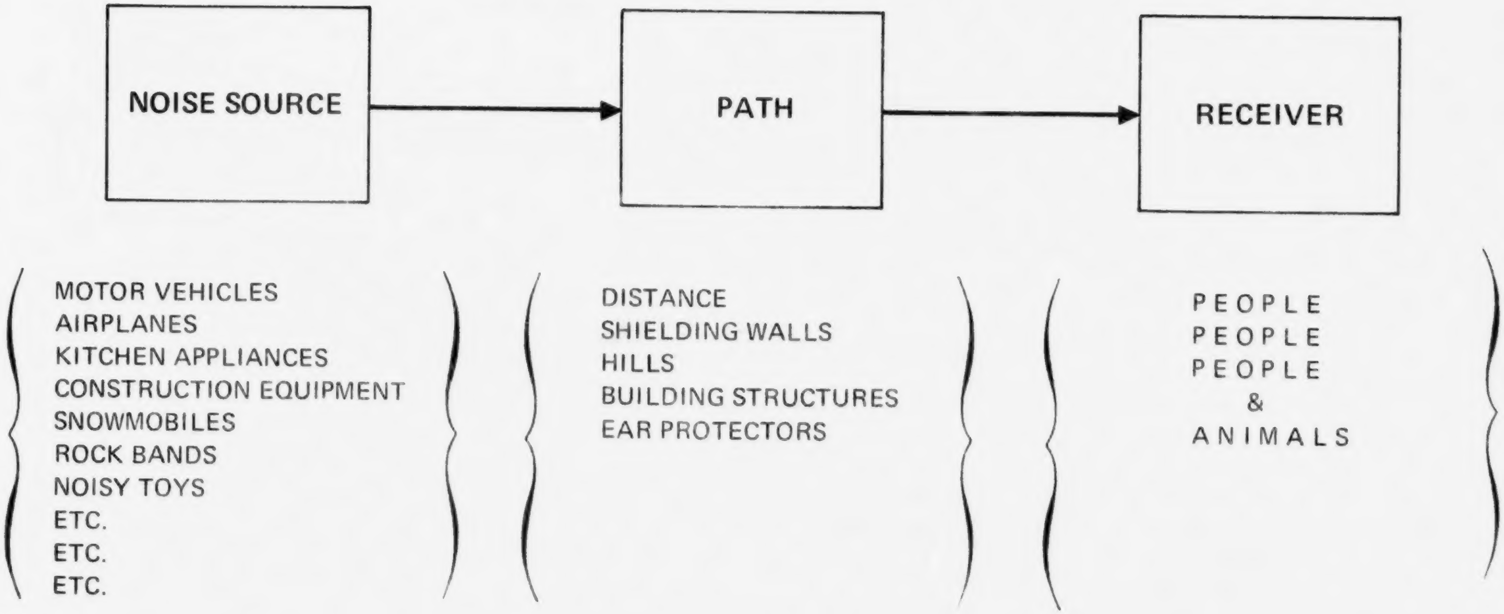
THE ELEMENTS OF A NOISE PROBLEM



NOISE SOURCE

MOTOR VEHICLES
AIRPLANES
KITCHEN APPLIANCES
CONSTRUCTION EQUIPMENT
SNOWMOBILES
ROCK BANDS
NOISY TOYS
ETC.
ETC.
ETC.

PATH

DISTANCE
SHIELDING WALLS
HILLS
BUILDING STRUCTURES
EAR PROTECTORS

RECEIVER

PEOPLE
PEOPLE
PEOPLE
&
ANIMALS

Figure 1

THE ELEMENTS OF PREVENTION/SOLUTION

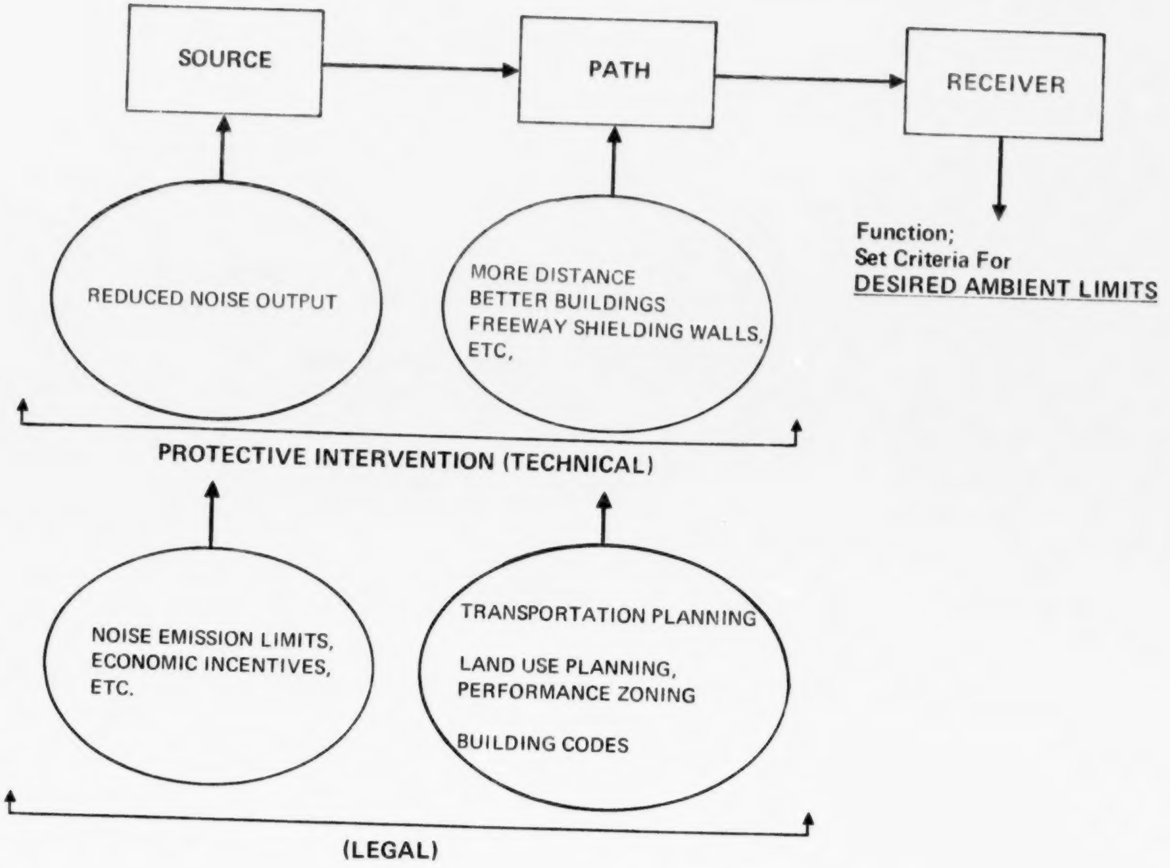

SOURCE
PATH
RECEIVER
Function;
Set Criteria For
DESIRED AMBIENT LIMITS
REDUCED NOISE OUTPUT
MORE DISTANCE
BETTER BUILDINGS
FREEWAY SHIELDING WALLS,
ETC,
PROTECTIVE INTERVENTION (TECHNICAL)
NOISE EMISSION LIMITS,
ECONOMIC INCENTIVES,
ETC.
TRANSPORTATION PLANNING
LAND USE PLANNING,
PERFORMANCE ZONING
BUILDING CODES
(LEGAL)

Figure 2

TWO SAMPLES OF OUTDOOR NOISE IN A NORMAL SUBURBAN NEIGHBORHOOD

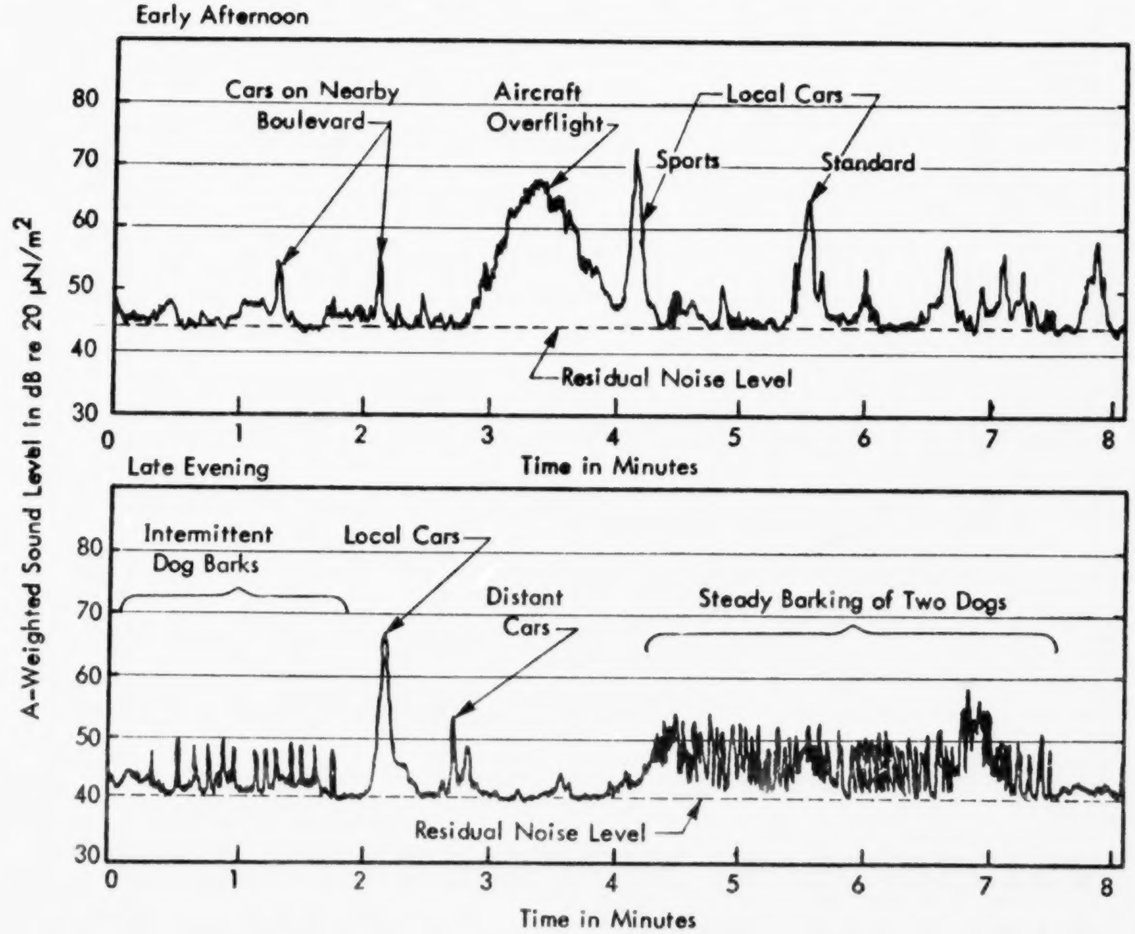


Figure 3

PASSENGER CAR AND DIESEL TRUCK OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA

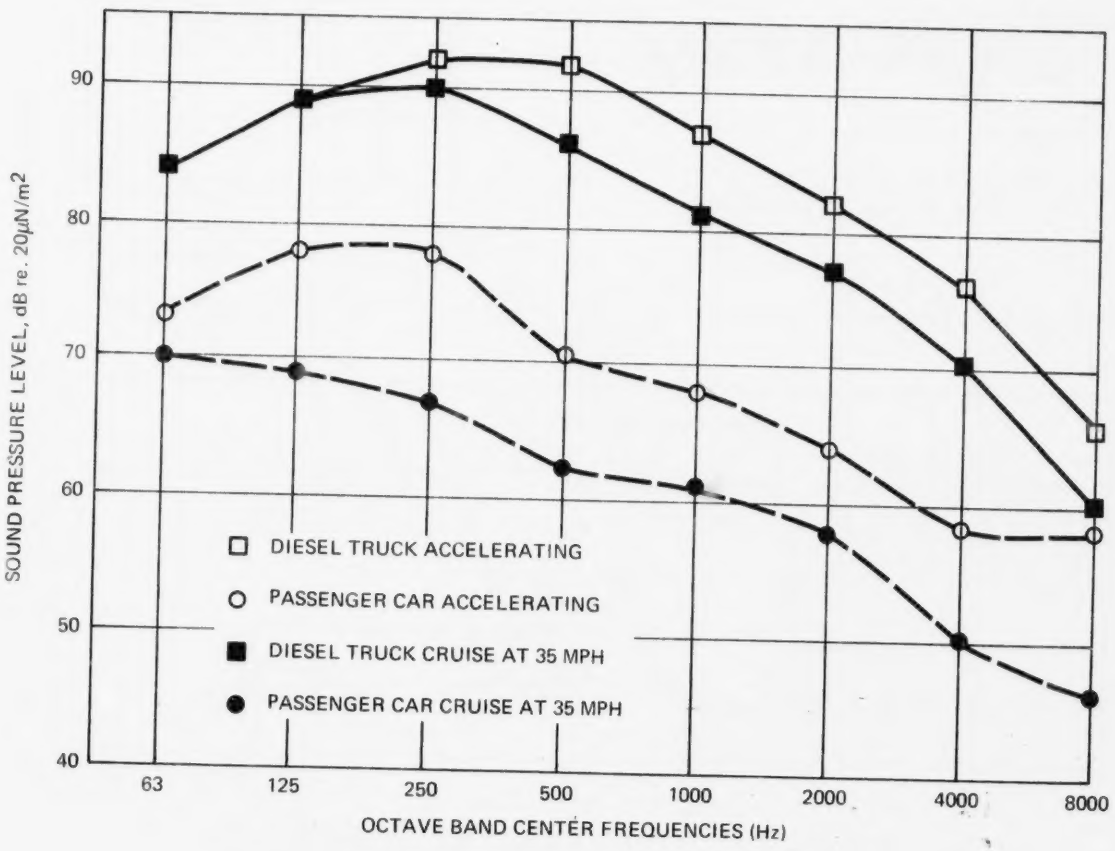
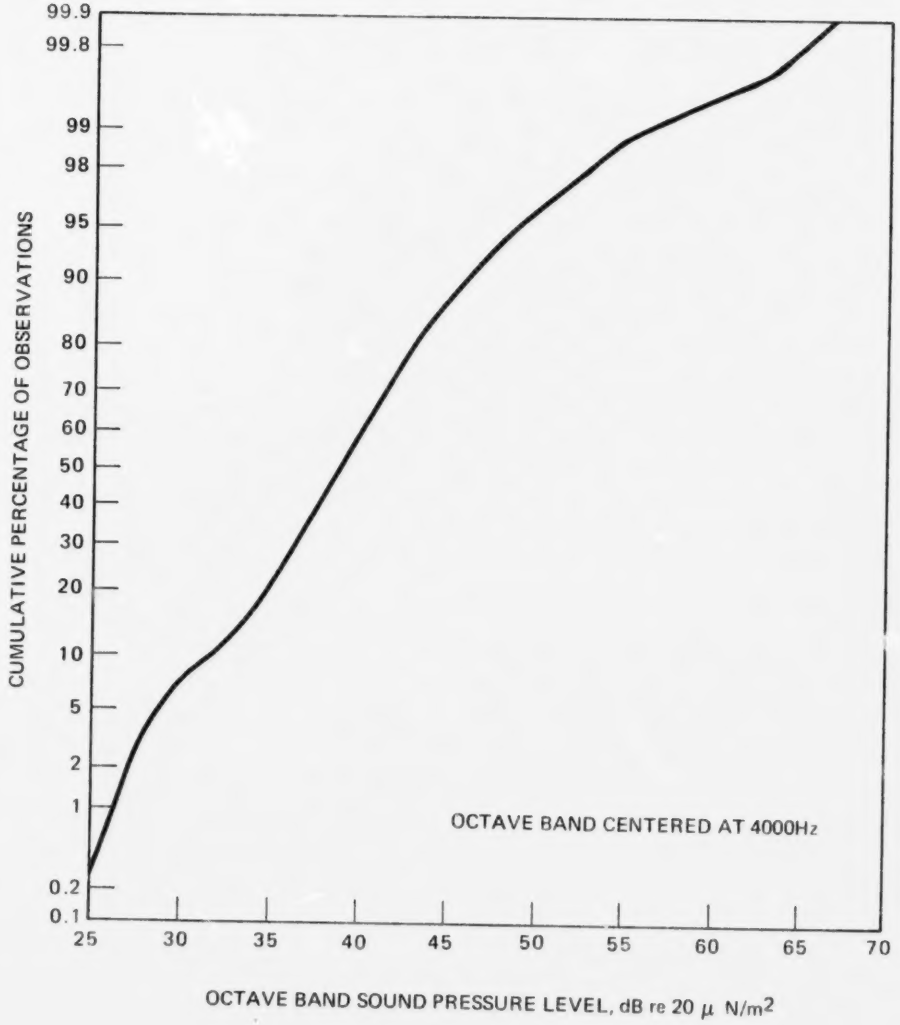


Figure 4



STATISTICAL REPRESENTATION OF COMMUNITY NOISE AT ONE POINT, OVER A GIVEN TIME PERIOD

Figure 5

IDEALIZED EXAMPLE OF NOISE CONTOURS AROUND AN AIRPORT

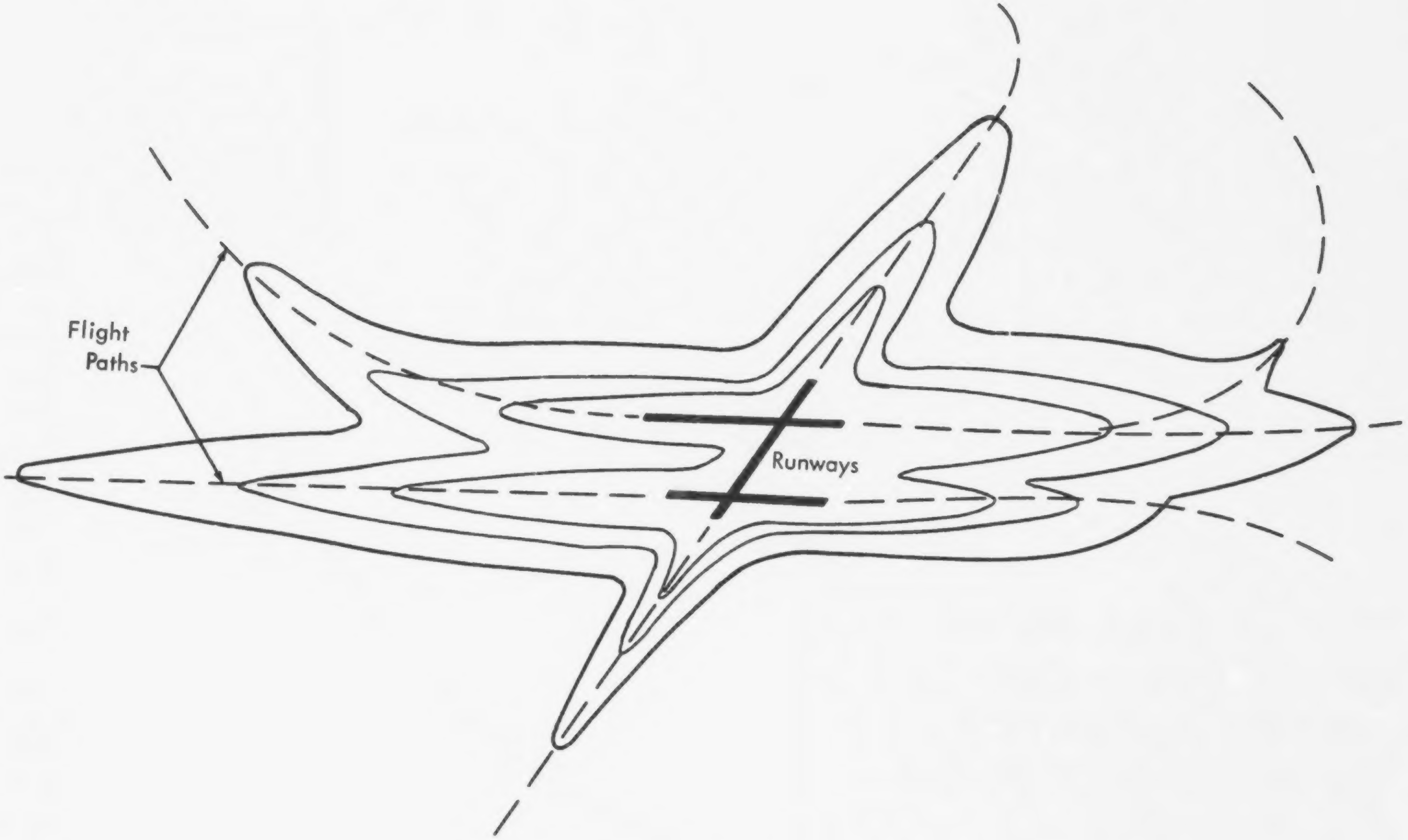

Flight
Paths
Runways

Figure 6

TWO TYPICAL HAND–HELD SOUND LEVEL METERS

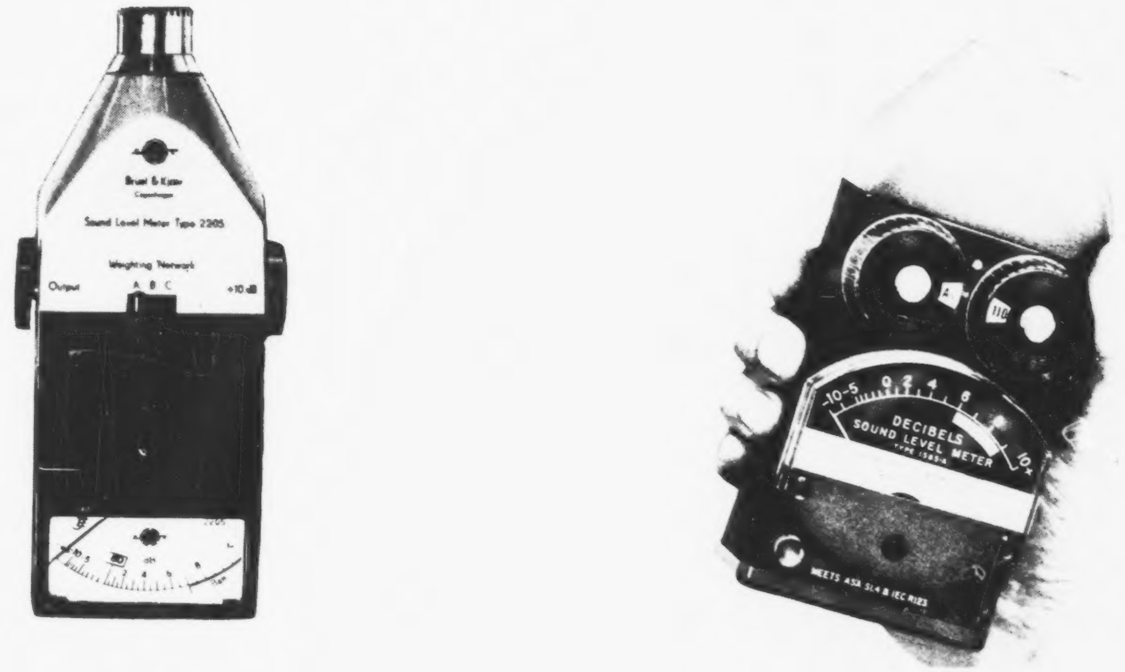

Brüel & Kjær
Copenhagen
Sound Level Meter Type 2205
Weighting Network
Output
A B C
+10 dB
-10 -5 0 2 4 6 10x
DECIBELS
SOUND LEVEL METER
TYPE 1565-A
MEETS ASA S1.4 & IEC R123

Figure 7

INTERNATIONAL STANDARD A, B, AND C WEIGHTING CURVES FOR SOUND LEVEL METERS

(D WEIGHTING UNDER CONSIDERATION)

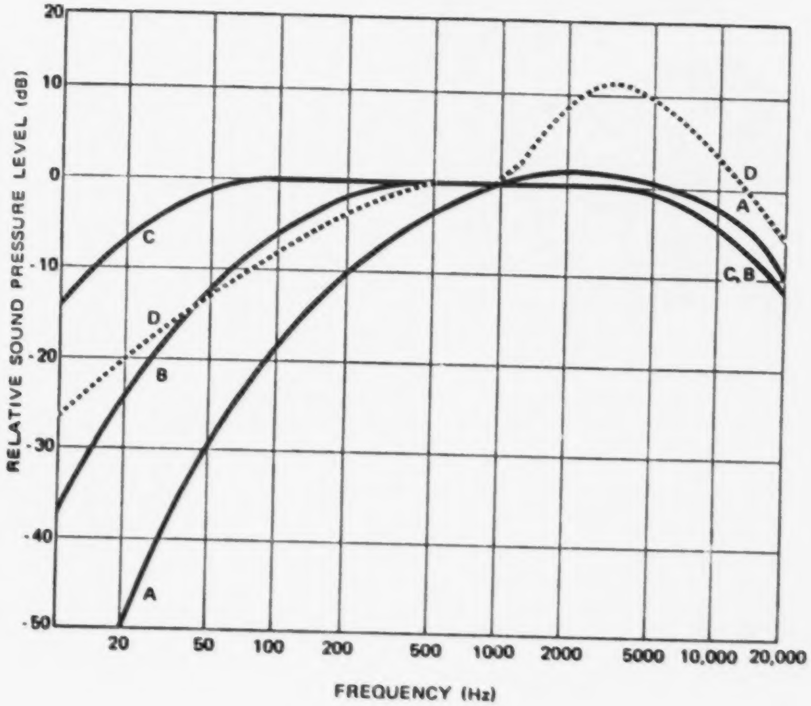


Figure 8

TYPICAL OCTAVE BAND SPECTRUM OF OUTDOOR RESIDUAL NOISE LEVEL, SHOWING THE EFFECT OF A–WEIGHTING

(LATE EVENING, NORMAL SUBURBAN NEIGHBORHOOD)

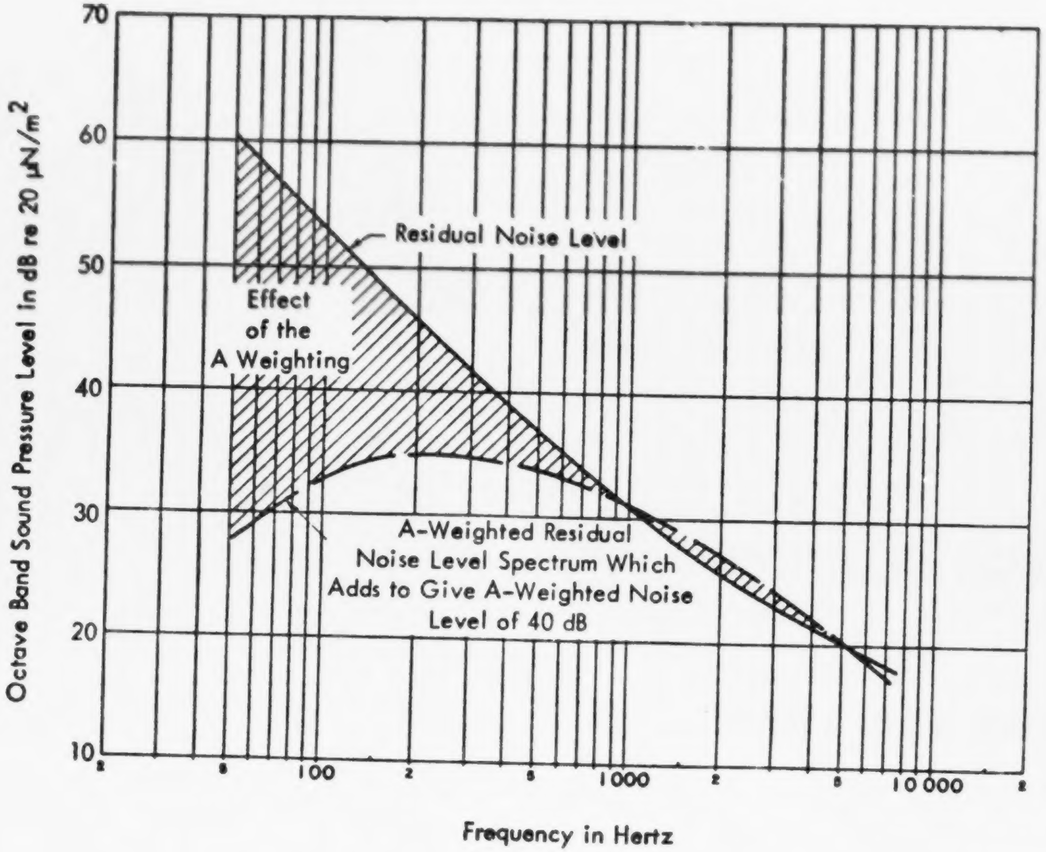
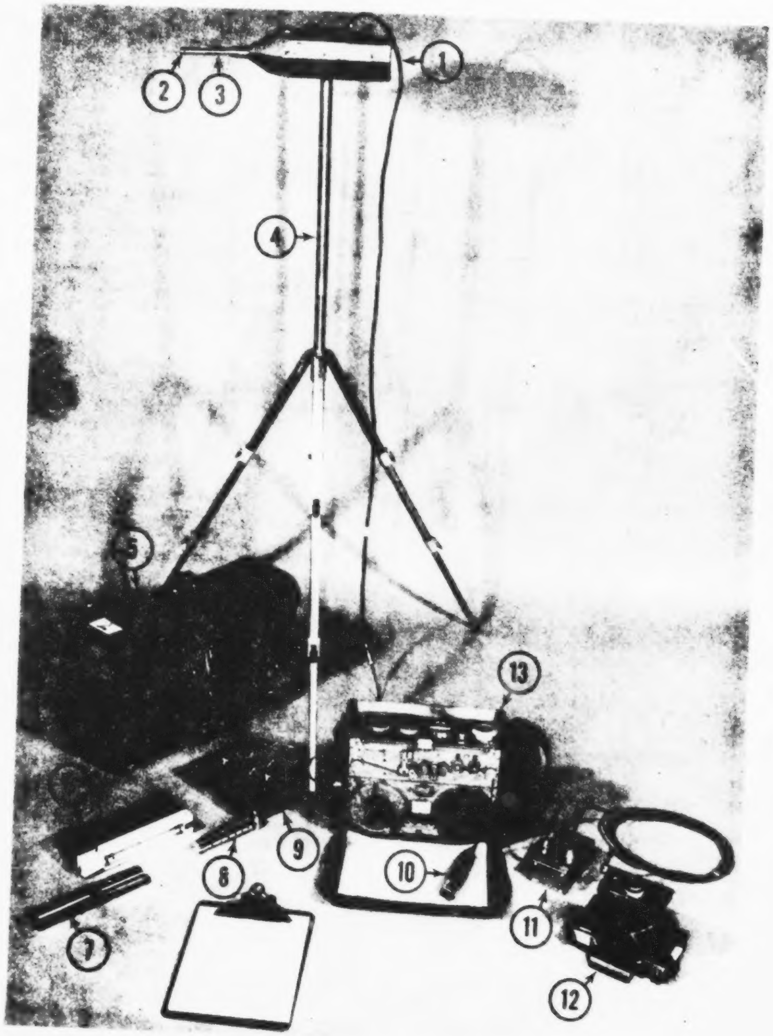


Figure 9



TYPICAL EQUIPMENT
FOR
FIELD ACOUSTIC RECORDINGS

Legend:

1 - Sound level meter
2 - Microphone
3 - Microphone adapter
4 - Tripod
5 - Carrying case
6 - Psychrometer
7 - Microphone calibrator (pistonphone)
8 - Windmeter
9 - Automatic octave-band center-frequency oscillator
10 - Cue microphone
11 - Sync generator
12 - Polaroid camera
13 - Tape recorder

Figure 10

BASIC EQUIPMENT FOR RECORDING AND STATISTICAL ANALYSIS

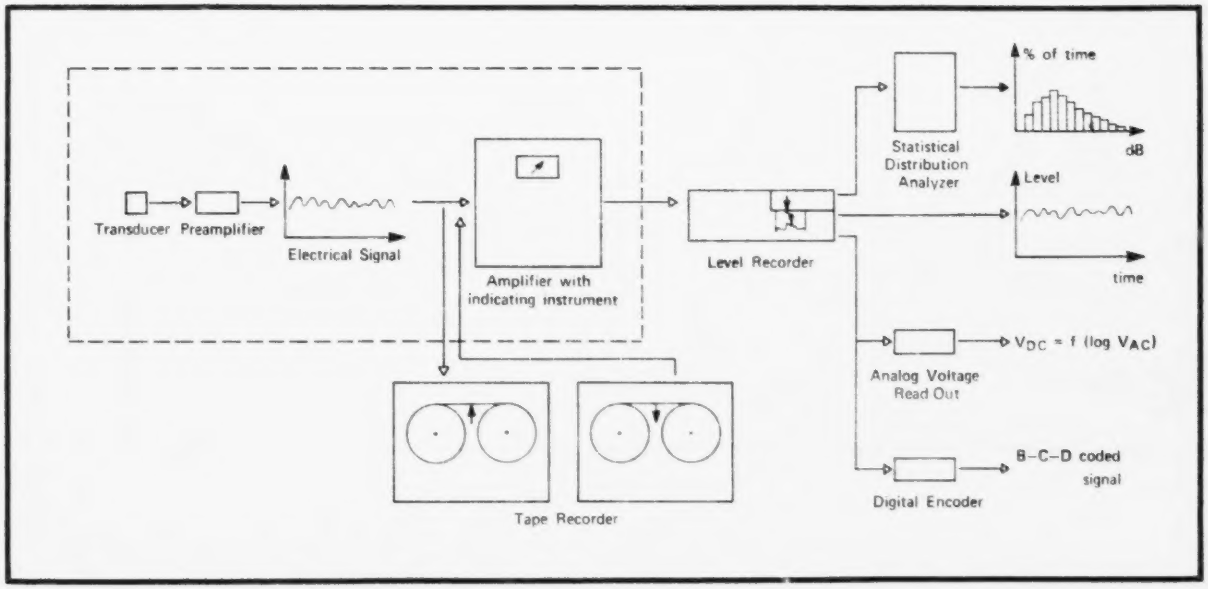

Transducer
Preamplifier
Electrical Signal
Amplifier with indicating instrument
Tape Recorder
Level Recorder
Statistical Distribution Analyzer
% of time
dB
Level
time
Analog Voltage Read Out
$V_{DC} = f(\log V_{AC})$
Digital Encoder
B-C-D coded signal

Figure 11

BASIC EQUIPMENT FOR REAL–TIME ANALYSIS
(FREQUENCY ANALYSIS AND STATISTICAL ANALYSIS)

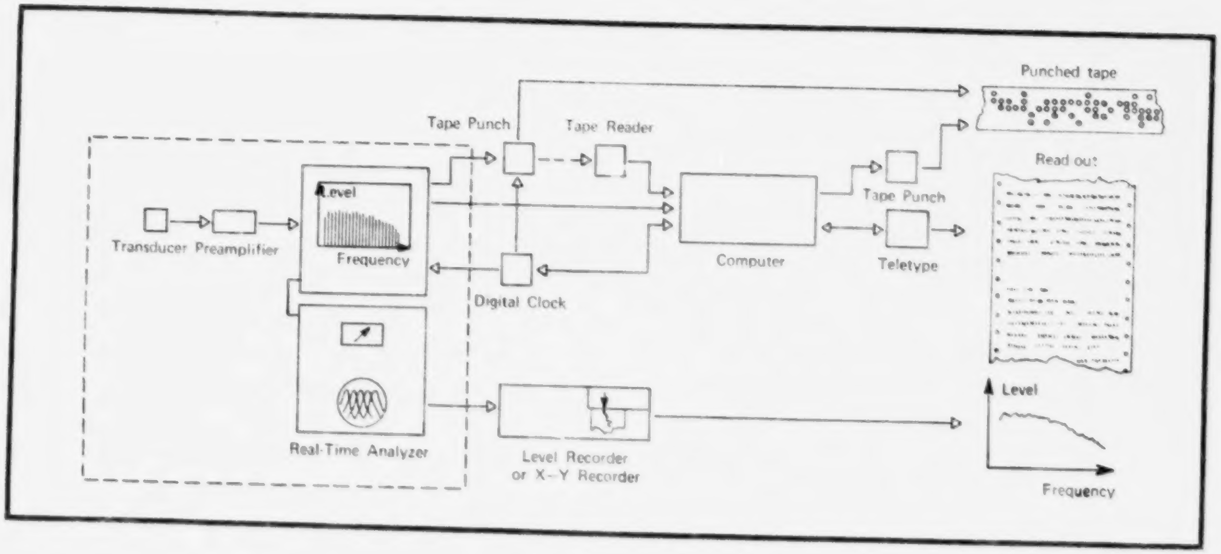

Punched tape
Tape Punch
Tape Reader
Read out
Level
Transducer Preamplifier
Frequency
Computer
Tape Punch
Teletype
Digital Clock
Real-Time Analyzer
Level Recorder
or X–Y Recorder
Level
Frequency

Figure 12

TYPICAL HOURLY NOISE LEVEL (HNL) SYSTEM

(CALIFORNIA AIRPORT NOISE REGULATION)

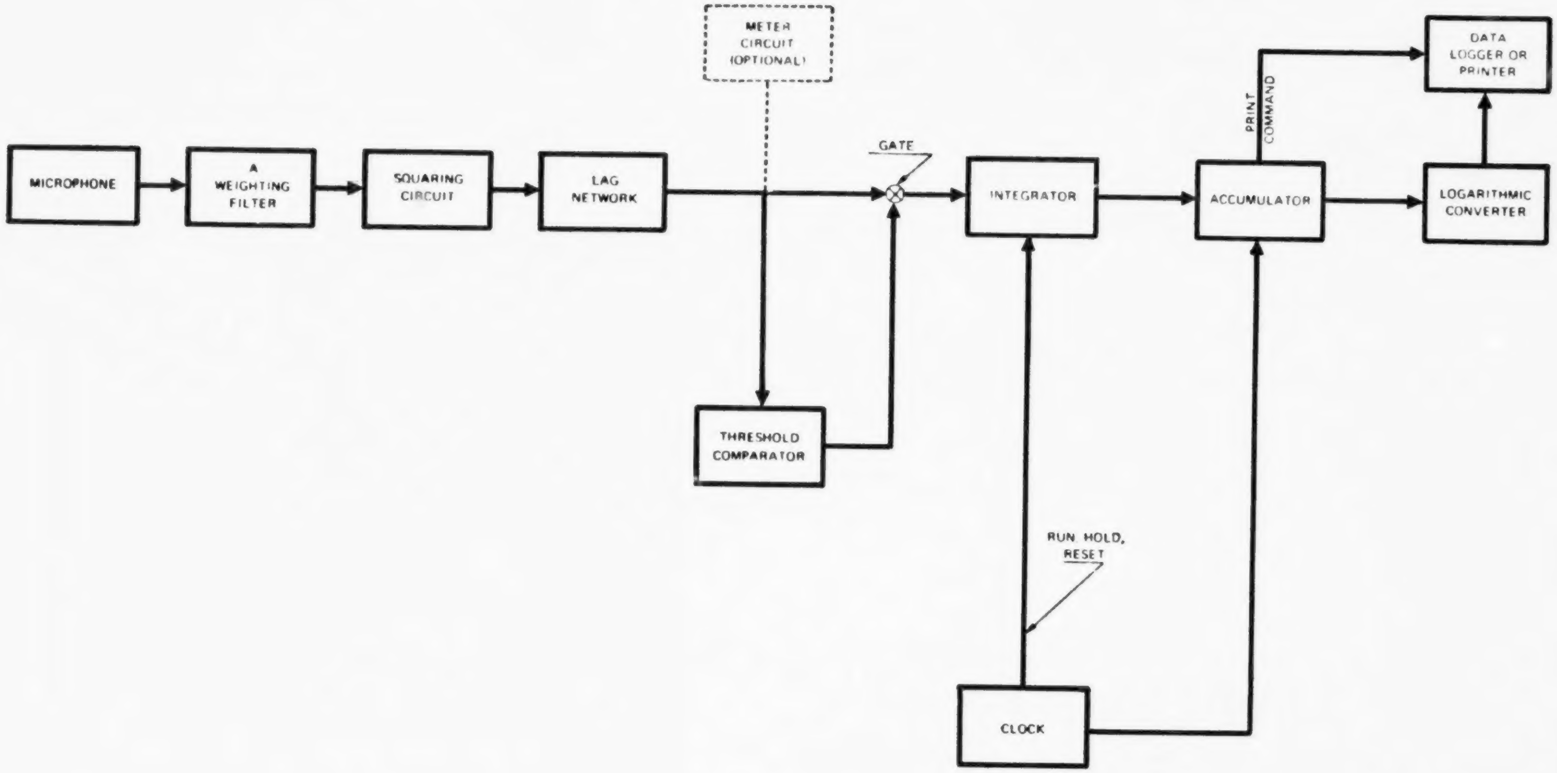
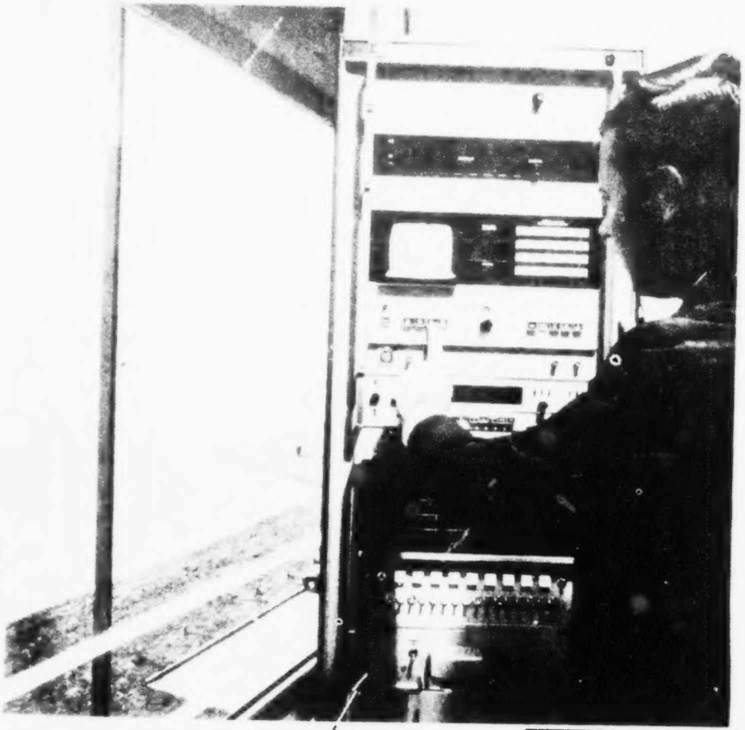

METER CIRCUIT (OPTIONAL)
DATA LOGGER OR PRINTER
PRINT COMMAND
GATE
MICROPHONE
A WEIGHTING FILTER
SQUARING CIRCUIT
LAG NETWORK
INTEGRATOR
ACCUMULATOR
LOGARITHMIC CONVERTER
THRESHOLD COMPARATOR
RUN HOLD, RESET
CLOCK

Figure 13

AIRPORT NOISE MONITORING
AT STUTTGART



Stuttgart's computerized system prints hourly and daily noise exposure index.

Numbers indicate locations of noise monitoring microphones and "Z" represents central measurement station at the airport.

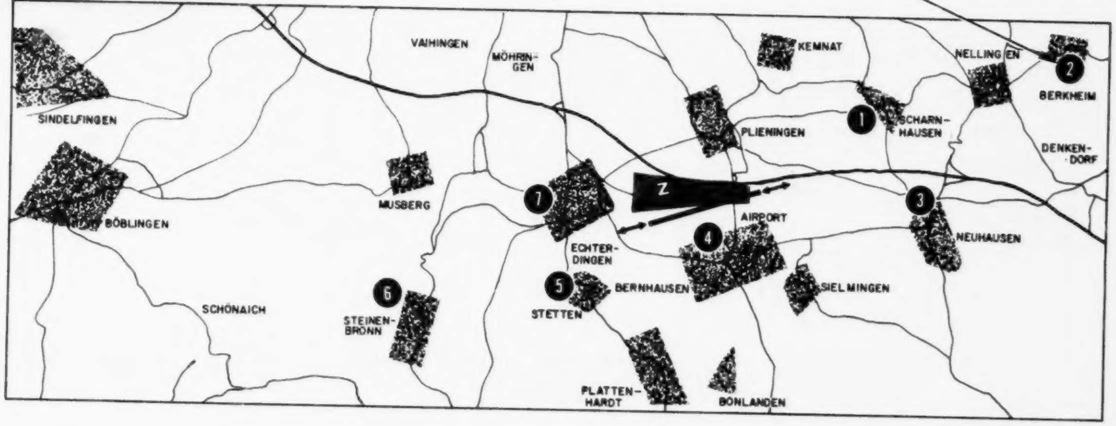
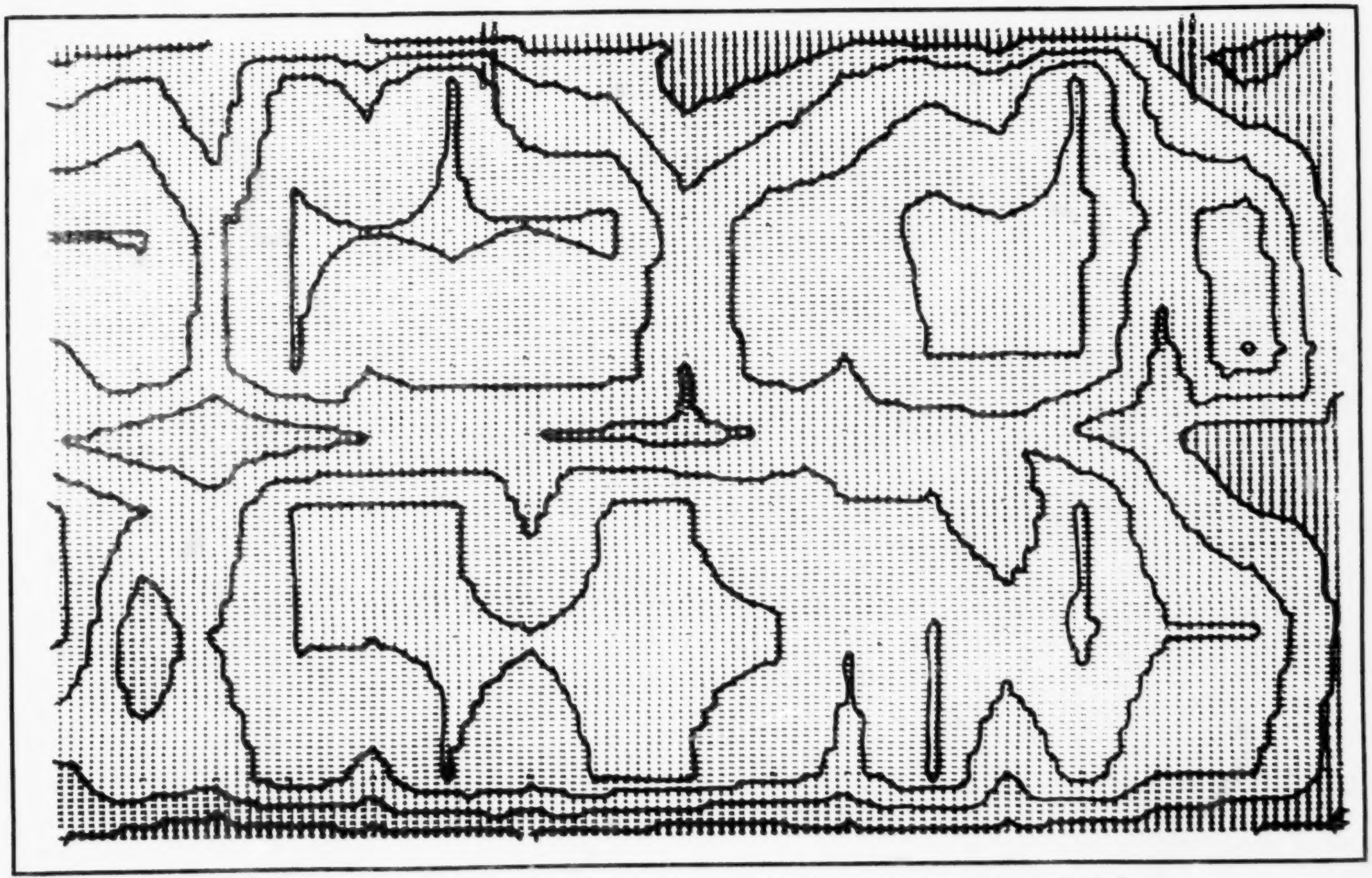

VAIHINGEN
MÖHRINGEN
KEMNAT
NELLINGEN
2
BERKHEIM
SINDELFINGEN
PLIENINGEN
1
SCHARNHAUSEN
DENKENDORF
Z
7
3
MUSBERG
BÖBLINGEN
AIRPORT
4
NEUHAUSEN
ECHTERDINGEN
5
BERNHAUSEN
SIELMINGEN
6
SCHÖNAICH
STEINENBRONN
STETTEN
PLATTENHARDT
BONLANDEN

Figure 14

AUTOMATED COMMUNITY NOISE MAPPING IN MONTREAL



Cartographie automatique en sept (7) catégories d'intensité du secteur étudié avec grande précision en 1969.

Figure 15

APPROACHES TO WATER QUALITY MONITORING

William T. Sayers
Office of Research and Monitoring
Environmental Protection Agency

INTRODUCTION

Water quality monitoring has been practiced on a more or less routine basis since the latter part of the 19th century. In the early days attention was directed almost solely toward bacterial pollution. Health authorities at that time mounted a massive Federal and State effort to combat water borne diseases, such as typhoid fever, which were prevalent then and into the early part of this century.

Since that time, attention has broadened to include many other measurements that have become necessary in order to fully characterize water quality and changes in it. Increased economic activity over the past 100 years has resulted in the introduction to our Nation's waters of many new polluting substances and increased amounts of many of the old polluting substances. There are presently an estimated two million known chemical compounds. Several thousand new chemicals are discovered each year. Most of them eventually find their way into the Nation's waters. This fact plus recognition that there are continual chemical and biochemical changes occurring in the receiving waters indicate to us that the water quality indices deemed to be of general interest may well continue to increase with time.

As the population and economic activity expand, water use and waste production will continue to increase. In another 10 years or so water use for municipal supplies, manufacturing, and irrigation will approach 650 billion gallons per day, which is equal to the total estimated dependable fresh water supply of the United States. These facts clearly indicate that water will have to be reused on a larger and larger scale in the future. To accomplish this, water quality will have to be effectively controlled through coordinated local-State-Federal water resource management programs.

Water resource management, in its highest sense, implies the systematic control and manipulation of all variables affecting water quality and quantity so as to maintain conditions that will yield the greatest over-all benefits. Effective water resource management requires the use of reliable and timely information on water quality. Thus, the key to effective water resource management is the ability and capability to monitor substances (and understand their behavior) in water. In addition, water quality monitoring serves as the best "yardstick" for evaluating the effectiveness of a water resource management program.

BASIC OBJECTIVES OF WATER QUALITY MONITORING

Water quality monitoring should be carried out with specific objectives clearly in mind. Basic monitoring objectives include:

1. The establishment of baseline water quality and identification of short- or long-term trends;

2. Evaluation of compliance or noncompliance with water quality standards;
3. Development of mathematical models for forecasting water quality under a variety of waste loadings and hydrological conditions; and
4. Obtaining data for input to existing models used in the day-to-day management of a water resource.

Monitoring carried out for the purpose of establishing baseline water quality and making trend evaluations will generally also serve to detect the emergence of adverse conditions before actual water quality standard violations occur. This permits action to be taken early to prevent a standards violation rather than later when the costs are greater. Thus, monitoring makes it possible for the water quality manager to spend his limited resources on "ounces of prevention" before damages occur rather than on "pounds of cure" after the damage is done. This is the essence of a true water quality management program.

Maintaining compliance with water quality standards will require not only the existence of adequate waste treatment and control facilities but also the operation of these facilities day after day at or above design efficiency. A monitoring program sufficient to detect serious temporary standards violations will serve to discourage intentional waste bypassing or shoddy operation of the treatment and control facilities. Such a monitoring program is essential in achieving full implementation of the State-Federal standards developed over the past several years.

The huge expenditure required for waste treatment facilities across the nation in order to achieve and maintain compliance with water quality standards and the limited funds available for this endeavor demand that the funds be utilized in the most cost-effective manner. Accordingly, wastewater management planning efforts must be sufficient to identify maximum permissible waste loads and specific treatment requirements in successive reaches along each water course. Plans must also identify where joint treatment of wastes from several communities is less costly than individual treatment by each community. These plans must identify not only current treatment needs but more importantly, the treatment requirements of each community or region at various dates in the future. This information will serve to ensure that all treatment facilities are constructed and in operation by the time they are needed.

Preparation of these water quality management plans requires the development and use of mathematical models relating waste discharge loadings to water quality in the receiving body of water. The development of a mathematical model, in turn, requires sufficient monitoring to completely characterize water quality in the receiving body under a steady-state waste loading and hydrological condition.

In areas of dense population, complex waste sources, intensive water use, and close hydrologic interrelationships, mathematical models may well be used by basin managers to identify day-to-day adjustments needed in reservoir releases, storage and releases of treated effluents, waste treatment operating efficiencies, and other control measures in order to maintain optimal water quality conditions. Such a management system will require continuous monitoring at key points in the basin in order to provide the necessary model input data.

MONITORING PROGRAM DESIGN CONSIDERATIONS

In the design of a monitoring program, the specific objectives to be served must be clearly in mind from the very beginning. Otherwise, the effort will probably not result in an efficient and meaningful program. The length of the survey, station selection, parameter coverage, and sampling frequency all depend on the specific objectives and the time-frame in which the objectives must be achieved. These variables also have a very significant impact on monitoring costs.

Monitoring for the purpose of establishing baseline water quality can generally be accomplished by intensive sampling over a one to two week period during each season of interest. If results are not needed for several years and the quality is not expected to change significantly during that period (e.g., in a wild river), then objectives can also be met by sampling at rather infrequent intervals over the entire period.

Monitoring for the purpose of mathematical model development requires intensive sampling of the waste sources and the receiving waters over a short time period. In that steady-state conditions are assumed to exist during a given sampling phase, it must be short enough so that variations in waste discharges and stream flow are minimal throughout the period.

Monitoring for the purpose of long-term trend identification, evaluation of standards compliance, or river basin management must, of course, be a continuing program without end.

The number and spacing of monitoring stations also vary considerably, depending on the objectives to be achieved. Baseline water quality evaluation can be achieved with a minimal number of stations providing sparse coverage of a vast area. Mathematical model development, on the other hand, requires a relatively large number of stations giving complete coverage of a small area.

The parameter coverage provided, likewise, varies with objectives. Baseline water quality and trend evaluations require measurement of all indices that are likely to be of interest in the future. Model development, conversely, requires evaluation of only those parameters being modeled plus the independent variables that influence the parameters of interest.

The sampling frequency necessary to characterize a body of water is related to the periods of cyclic phenomena which control quality and to random influence, mostly associated with meteorologic and hydrologic events. The number of time-dependent factors which must be considered depends on the type of water body in question, the wastes being discharged, and the particular parameter of interest. Generally, temporal variations in water quality are least frequent in large impoundments and most frequent in rivers.

The actual number of samples required over a given time period at each station to characterize water quality, in essence, depends on the variability of the parameters of interest, regardless of the number and kinds of influencing factors. In a statistical sense, there is no answer to the question of how many samples are needed, without foreknowledge of the variability of the parameter to be sampled and the precision desired. It can only be said that enough samples should be collected to define, at a specific level of significance, the water quality response caused by the imposed influencing factors (e.g., pollutant load, manipulation of stream flow, tidal conditions, and sunlight). The adequacy of the number of samples taken in a given period can be judged by the magnitude of the 95 percent confidence interval.

Often, too many stations are established with an insufficient number of samples collected at any one. A fewer number of stations with a sufficient number of samples to define results in terms of statistical significance is much more reliable than many stations with only a few samples at each. Sampling (for the purpose of describing a given condition) should not be spread over a long time interval during which the receiving water regimen is subject to a wide variety of conditions. Attempts to assess all conditions by an aimless sampling program usually defines no condition and, in fact, may be very misleading. Averaging of such noncomparable results is often a risky procedure. Instead, the sampling program should be designed so that each condition of interest is defined rather than attempting to define all the conditions (resulting from hydrologic, hydraulic, or hydrodynamic variations) by merely "averaging" them together.

Another factor which influences the number of samples required in a given time period is the precision of the test for the given parameter being measured. If, for instance, mean temperature and coliform density (MPN) were to be evaluated under steady-state conditions at some point in a small well-mixed stream, a greater number of coliform samples (minimum of about 16) than temperature samples (minimum of about 3) would be required for an equal degree of reliability in the results. This is because the MPN test procedure is subject to a much wider variation than the temperature test. Hence, when several parameters are being measured at a given site, the number of samples collected should be sufficient to satisfactorily evaluate that parameter tested by the least precise method.

Given a large number of samples collected at short time intervals, the results obtained can be analyzed to determine the optimum frequency for meeting a given set of objectives. Within the realm of practicability, however, this is seldom possible. Judgement must be used in arriving at a first approximation of the optimum frequency. Where the objective is to determine trends in water quality on a wild river, a sampling frequency that will require several years in order to accumulate sufficient data to make an evaluation may be satisfactory. On the other hand, where the objective is to spot violations of standards in waters of marginal quality, a much greater frequency would be required—one that permits the accumulation of sufficient data to draw conclusions in a matter of hours or days, depending on the value of the resource affected.

Evaluations to be made with the water quality data collected are generally not possible without some additional data on hydrological, hydrographic, and meteorological conditions during the period of the monitoring survey. If, for example, the evaluation is of a stream, information is needed on the stream discharge rate during the sampling period and the historical flows.

When the objective includes development of mathematical models for establishing cause-effect relationships, information on times-of-flow at a range of stream discharge rates is essential. This requires the measurement of velocities along a stream at a minimum of three different stream discharge rates. Dye tracers lend themselves very well to studies of this type. If reaeration rates (using the O'Connor-Dobbins formula) are to be included in a mathematical model, then stream depths must also be measured for a range of discharge rates. For most free-flowing streams, a plot on log-log paper of stream discharge rate versus velocity and depth will result in straight lines, thus permitting interpolation between actual measurements.

Studies of open waters (e.g., large impoundments, lakes, estuaries, and coastal waters) often require that several meteorological measurements be made. These include wind speed and direction, air temperature and humidity, solar radiation intensity, and tidal cycles. The meteorological parameters actually evaluated depend on the relationships that are to be established. If it is mixing and/or flow patterns, then wind speed and direction would be important; if it is the dissipation of heat resulting from a source of thermal pollution, then air temperature and humidity, in addition to wind speed, would be of interest.

WATER QUALITY MONITORING TECHNIQUES

Earliest water quality monitoring techniques employed the collection of grab samples using a bucket suspended from a rope with sample analysis carried out manually on the stream bank or in a nearby laboratory. This approach is still in wide use today. The reason for its continued use is not so much due to its outstanding advantages as it is to the fact that there is no alternative technique available for achieving the same objectives.

Early attempts to improve on the state-of-the-art of water quality monitoring centered largely around automation of the sample collection and laboratory analysis phases. There are numerous automatic sample collection devices on the market that can be timed to obtain discrete grab samples at predetermined intervals and to even composite the samples in proportion to wastewater flow rates. At the end of the sampling period, the station must be visited, the sample or samples picked up and then hand carried to the laboratory for analysis. These samplers are designed primarily for use on effluent lines rather than in open waters, however.

Many of the laboratory analyses that were formerly carried out manually have now been automated. Newer laboratory instrument designs have incorporated automatic sample handling, sequential analysis, and improved data presentation. Many instruments are capable of withdrawing an aliquot of sample, performing the measurement, and presenting the data as concentration of the constituent, in printed form. Connection of analytical instruments directly to a computer to eliminate all manual operation from sample aliquot withdrawal to final data storage is possible in some situations. This approach will very likely be employed to a greater and greater degree in the future.

Some of the newer instruments found in routine use today in many laboratories include:

- Automatic Titrators
- Technican Autoanalyzers
- Total Carbon Analyzers
- Specific Ion Meters
- Gas Chromatographs
- Atomic Absorption Spectrophotometers
- Infrared Spectrophotometers

EPA and its predecessor agencies concerned with water analysis have long recognized the need for automatic field instrumentation capable of giving a direct and instantaneous read-out of the levels of specific water quality indices. Work was begun in 1953 by the former U. S. Public Health Service Division of Water Supply and Pollution in cooperation with the Hays Corporation on the development of such a device for the continuous measurement of dissolved oxygen. Other work of a similar nature soon followed. Efforts centered on the development of sensing devices utilizing a direct electrical response mechanism. This work led to the preparation in November 1962 by Mr. A. F. Mentink of the first set of Public Health Service specifications for an integrated multi-parameter water quality data acquisition system. Mr. Mentink of the Analytical Quality Control Laboratory in Cincinnati is now engaged in the preparation of the ninth edition of these specifications.

Of those parameters of general interest in water quality surveys, to date, eight of them can be reliably measured by continuously operated electronic sensors placed in the field. These are pH, temperature, dissolved oxygen, specific conductivity, chloride, turbidity, oxidation-reduction potential, and solar radiation intensity. Results can be recorded on site or telemetered to a central location.

Many portable single parameter electronic sensors are also presently on the market. They are of considerable value in the conduct of short-term intensive surveys and for reconnaissance purposes.

Another rather recent monitoring technique that may eventually have significant application in the evaluation of water quality is remote of spectral sensing from aircraft or satellite. It has the potential to provide rapid overall assessment of pertinent river basin characteristics, such as population distribution, land and water uses, and location of waste sources, as well as to provide information on the physical, chemical, biological, and hydrographic characteristics of surface waters.

Spectral sensing in the infrared range is particularly useful in measuring variations in water surface temperature over wide areas.

Natural color photography is also quite useful in that it provides a true "bird's eye view" of large water areas and permits a rapid qualitative evaluation of visible pollution problems. Locations where quantitative evaluations would be most meaningful are thus immediately identified.

Although the application of remote sensing technology to water resource management has really just gotten under way, the present state-of-the-art is already rather impressive. Remote sensing is expected to play an increasing role in future water quality management programs.

AUTOMATED VS. MANUAL MONITORING TECHNIQUES

Electronic monitors and aerial remote sensing techniques significantly increase our technical capability to monitor surface waters on a continuous or near-continuous basis. However, they are not a panacea.

In terms of evaluating compliance with water quality standards, only one parameter of interest, temperature, can presently be measured quantitatively using remote or spectral sensing techniques. Electronic sensors provide a little more versatility in that they are capable of measuring six parameters likely to be found listed in water quality standards. This leaves 50 or so parameters contained in or alluded to by the standards for which no alternative for evaluation other than manual sample collection and separate laboratory analysis exists.

For those parameters where there is a choice between manual and automated monitoring techniques, the decision on which approach to pursue should be based on economic considerations. Once the number and location of stations, the parameter coverage, and the minimum necessary sampling frequency have all been identified, the cost of each alternative approach can then be determined. The least costly alternative should, of course, be the one implemented.

When comparing the flexibility and relative costs of manual sampling and analysis versus electronic monitoring, the following points should be considered:

1. Electronic monitors do not completely replace field personnel. Each monitoring site should be visited at least weekly for routine maintenance and recalibration. Equipment malfunctions may require more frequent visitations. Higher salaried personnel may be required for monitor maintenance than for manual sample collection.
2. Automated monitoring system data handling costs will vary, depending on whether analog or digital output is used. In either case costs will generally be greater than if manual techniques were used. The type of output selected depends on the evaluation procedure and ultimate use of the data which must be fully considered in the design phase of the sampling program.

Generally the most important single factor in determining whether manual or automated techniques should be used is the monitoring frequency that is required. In the manual approach, monitoring costs vary almost directly with measurement frequency. At monitoring frequencies much greater than once per week, automated sensing will generally prove to be the more economical approach, provided that appropriate sensors exist.

MONITORING INSTRUMENTATION NEEDS

As water is reused to a greater and greater degree in the future, more sophisticated water resource management programs will be necessary. To function, they must have the capability to acquire timely information on water quality over vast areas on a day-to-day basis. This capability does not exist today. To achieve this capability, further research and development are needed on:

1. Low cost automated (portable and fixed) water quality sensors that can measure a wide variety of indices over long periods with minimal maintenance.
2. Aerial remote sensing techniques for broad-scale evaluation of water quality conditions over vast geographical areas.
3. New, more inclusive water quality indices that can better lend themselves to automated and remote sensing techniques. Instead of describing water quality changes using indices such as dissolved oxygen, BOD, etc., perhaps consideration should be given to the use of indices indicative of changes in emission or reflectance of certain energy spectra from a given water body. As long as the changes in emission or reflectance were a result of changes in water quality conditions and were generally proportional to the overall water quality

changes, this would be a useful approach. In fact, this may be all the monitoring needed after 1985 to enforce water quality standards on navigable waters, if Senate Bill 2770 is passed as written. The bill proposes that the discharge of pollutants into navigable waters be eliminated by 1985.

SUMMARY

In summary, much of the water quality monitoring as carried out today is not drastically different from the ways in which it was conducted at the beginning of this century. Most of the improvements in methodology made over the past 50 years have been in laboratory as opposed to field techniques. The development of automated electronic sensors for the measurement of a few parameters has, nevertheless, proven to be a significant step toward meeting the field needs of tomorrow. Recent developments in remote sensing also offer much promise.

One point is certain; if we want to begin thinking of ourselves as true water quality managers we must act to prevent water quality problems, not merely react to water quality problems that have been permitted to occur. Prevention of water quality problems requires early detection of emerging adversities, and early detection is not possible without adequate monitoring tools and a fully implemented monitoring program. Efforts are presently under way to provide the necessary tools and an adequate monitoring program. These efforts must be intensified, however, if we are going to make the transition from the reaction to the action phase by the time the present backlog of pollution problems has been corrected.

IN-SITU AND REMOTE SENSING FOR SOLID WASTES

Harry Stierli
Solid Waste Research Division
National Environmental Research Center
Environmental Protection Agency
Cincinnati, Ohio

INTRODUCTION

The purpose of this paper is to provide information on the state of the art and current techniques for monitoring of pollutants caused by solid wastes. Although at this Workshop we are concerned primarily with sensors for monitoring environmental pollution, some background and related material will be presented in explanation of solid waste management problems and those parameters indicated for detection, measurement and analysis.

All of us should be aware that storing, collecting, transporting, processing and disposing of solid wastes can cause pollution to our environment. For example, dumps and landfills are potential sources of gaseous and liquid effluents for contamination of the surrounding air, land and water.[1] Likewise, incinerators, recycling plants and other solid waste processing facilities may discharge toxic or otherwise objectionable meterials to the atmosphere, streams and land.

Pollution from solid waste differs from air and water pollution in that it tends to be more of a local problem. Air and water carry pollutants across political boundaries in response to natural laws. In contrast, solid wastes are left where they are generated or are transported mechanically.[2] The solid wastes in a landfill remain stationary and tend to retain their physical and chemical characteristics. Decomposition of the material is relatively slow, and the products of decomposition are localized and concentrated. The major pollution effects are caused indirectly by decomposition products rather than the wastes themselves.[3] For example, the leaching of breakdown products and soluble materials from buried wastes may escape and contaminate ground and/or surface waters. Likewise, stack discharges from an incinerator may discharge particulate matter and noxious gases into the atmosphere. These effluents from landfills and incinerators also may contain toxic materials such as lead, cadmium, zinc, mercury, selenium, pesticides and polychlorinated biphenyls (PCB). Although their presence usually is in small amounts, they can have a significant public health effect. With pollution caused by solid wastes being primarily from gases, liquids and particulates that enter the air and water for transport, the sensing techniques are the same or similar to those used in the air and water programs. However, airborne remote sensing techniques such as multispectral aerial photography and aerial thermal mapping may prove useful for landfill site evaluation.[20]

At the Environmental Protection Agency's National Environmental Research Center, Cincinnati, scientists and engineers are working toward improved techniques for monitoring pollution and solving environmental problems. And we have noted how pollution of one media, land in the case of solid waste, leads to pollution of other media, as I've already mentioned. We see the need, and we hope everyone sees the need of considering the total environment when dealing with a particular problem.

SOLID WASTE INFORMATION NEEDS

A variety of information is needed to manage solid wastes for economic, aesthetic and environmental reasons. Table I lists some of the types of data needed for purposes of administration and management, research and scientific knowledge, and pollution surveillance. Solid waste management requires information on waste quantities and characteristics, practices, cost and performance of systems, manpower, effects of solid wastes on the environment, legislative regulations and related data. The 1968 National Survey of Community Solid Waste Practices[4] provides a baseline for some of the administrative and management data needs.

A systems analysis study of the container-train method of solid waste collection and disposal is being conducted by the City of Wichita Falls, Texas, under a demonstration grant supported by the Environmental Protection Agency.[5] In this study a municipal solid waste data system is being developed to collect operational information on a specific solid waste system. Solid waste weight data from both fixed containers and container trains is collected in the field and transmitted to the city's data processing center by means of a transmitter located in a compactor truck equipped with front end loader. The loader is instrumented with strain gauges which are calibrated to provide accurate weight of each load lifted.

Physical and chemical parameters and methods for solid waste characterization have been listed in a research report.[6] The following eight parameters were selected for special evaluation: biochemical oxygen demand of incinerator quench water, carbon, hydrogen, nitrogen, moisture, ash, volatiles, and calorific value. Research reports on the methods of analysis of these parameters are available for selected distribution.

It was necessary to modify a macroanalytical technique for accurate analysis of carbon in the solid wastes sampled prior to incineration and the residues following the incineration process.[7] This method provides both carbon and hydrogen content of samples employing a dry combustion-purification-gravimetric approach. Figure 1 shows the carbon-hydrogen train with the essential accessories in a laboratory. This method can accurately analyze 1- to 10- gram samples with carbon contents ranging from 0.46 to 83.31% and with hydrogen contents from 0.01 to 7.80%.

For convenience, research and pollution surveillance monitoring needs will be discussed in the following sections in relation to the methods by which the solid wastes are processed or disposed.

INCINERATOR EVALUATIONS

A number of municipal solid waste incinerators have been tested and evaluated by the Solid Waste Management Program of the Environmental Protection Agency.[8] Data were gathered on (1) the quality and quantity of solid waste processed, residue and gasborne particulate emissions, (2) the quality of the fly ash collected and the wastewater produced, and (3) the economics involved in incineration. Some of the information from these tests and related studies will be presented to illustrate special methods and parameters of interest concerning the characterization of wastes, evaluation of performance, and measurement of pollutants.

Standard stack sampling methods were used for measuring particulates and gases emitted from the incinerator stacks.[9] The effluent gases were sampled and analyzed for moisture, carbon dioxide, carbon monoxide and oxygen. Particulate emissions were in excess of all but the most lenient air pollution emission standards.

Process waters used in cooling and scrubbing emission gases and particulates, and in quenching the ash residue were sampled to determine pertinent physical and chemical characteristics. The major sources sampled were the incoming water, scrubber water, residue quench water and plant effluent. Temperature and pH of all samples were measured immediately after collection. After the samples were returned to the laboratory, they were analyzed for alkalinity, chlorides, hardness, sulfates, phosphates; conductivity and solids.[10] The process waters were contaminated, and although several plants have primary treatment facilities, further treatment should be required before being discharged into the environment.

Microbiological sampling techniques and analytical procedures have been developed for incineration testing.[11] Samples of solid waste and its residue after incineration were taken from eight incinerators of different design and examined for (1) total bacterial cell number, (2) total coliforms, (3) fecal coliforms, (4) heat resistant sporeformers and (5) selected enteric pathogens. Of the eight incinerators tested only one produced residue free of fecal coliforms. Salmonella organisms were found in the quench water and quenched residue at one of these incinerators.

A sampler was designed and used to measure microbial cell concentrations in incinerator stack emissions. Samples taken from the stack of a conical burner showed that a few viable gram-positive bacilli were emitted, but most of the organisms were scrubbed out.

Quantitative studies were made on the microbial flora of dust from six municipal incinerators using an Anderson sampler. The incinerator dust was found to carry pathogenic microorganisms, such as Staphylococcus aureus, Diplococcus pneumoniae, and Klebsiella pneumoniae, although these represented a small percentage of the total number of organisms. These organisms are associated with skin and the upper respiratory tract ailments. Escherichia coli was found in the dust at five incinerators tested, indicating the presence of fecal wastes.

LANDFILL EVALUATIONS

The principal means of disposing municipal solid wastes in the United States will continue for many years to be landfills. For purpose of this paper landfills include objectionable dumps as well as sanitary landfills. When wastes are buried in a landfill, the material decomposes by a combination of biological, chemical and physical processes.[12] Although the first stages of decomposition may be under partially aerobic conditions, succeeding stages are primarily anerobic in nature.

Gas production in landfills occurs from biological decomposition with the major constituents being methane and carbon dioxide. However, other gases such as nitrogen and hydrogen sulfide may be present. These gases are of importance when evaluating the effect a landfill may have on the environment because methane can explode and carbon dioxide may dissolve to form carbonic acid with resultant mineralization of ground water.

The principal way decomposition products from a landfill reach the surrounding environment is through leaching. Production of leachate may occur when ground water or infiltrating surface water moves through the solid wastes. Leachate may leave the fill at the ground surface as a spring or percolate through the soil and rock underneath and surrounding the waste. Table 2 provides data from two studies which indicate the quality of leachate from municipal solid waste.[12]

Hydrogeologic and water quality studies of five landfills in northeastern Illinois were carried out over a four year period in a Solid Waste Demonstration Grant Project. The final report of this project provides information on equipment and methods used for monitoring of the leachates from these landfills.[13]

Methods and equipment for sensing gaseous pollutants from landfills are described in a recent paper.[14] Portable combustible gas indicators are available for measuring methane, oxygen and hydrogen sulfide.

Figure 2 shows components of a gas sampling probe combined with thermocouples and thermistors for collecting gas samples and measuring temperature in an experimental landfill. These sensors are used for monitoring at the experimental Boone County Field Site in Kentucky where the Disposal Technology Branch of the Solid Waste Research Division, NERC, Cincinnati, is conducting field studies on land disposal of solid wastes. Gas samples are collected in glass flasks valved to allow simultaneous exhaust of the flask and aspiration of the sample into the flask. The samples are taken to the laboratory for analysis by a gas chromatographic method.

Figure 3 indicates schematically the gas chromatograph set up for sampling and analysis of landfill gases. The thermal conductivity detector is used for measurement of oxygen, nitrogen and carbon dioxide to values as low as 100 ppm. Methane and other hydrocarbons are measured simultaneously with the flame ionization detector to values as low as 1 ppm.

OTHER PROBLEM AREAS

Toxic materials such as mercury, lead, cadmium, zinc and selenium are present in solid wastes. Generally the amounts are small and do not constitute a health hazard. However, these materials may be concentrated in incinerator stack emissions and wastewater. Quantitative measurements have been made on selenium in paper, municipal solid wastes, incinerator stack emissions, incinerator quench waters, incinerator residue and compost samples using a spectrophotofluorescence method.[15]

Waste organic materials such as polychlorinated biphenyls (PCB) and pesticides (DDT, Aldrin, Malthion, etc.) present an increasing problem of disposal. A study of the decontamination and combustion of organic pesticides and pesticide containers was recently completed by Foster D. Snell, Inc. under a contract with EPA. Pyrolysis decomposition products of the pesticides were analyzed using a gas-liquid chromatograph and a differential scanning calorimeter.[16]

Special problems of industrial hygiene and environmental pollution may occur in processing reclamation plants where solid wastes, sewage sludge and other organic wastes are selectively recycled, shredded, pulverized and converted into useful products by composting or other means. Hammermills and other grinders of the wastes produce dust and noise that can be hazardous to the workers in the plant. Such plants are potential sources of odors and may provide breeding places for flies and rodents. The gaseous and liquid effluents from these plants may require monitoring to assure that objectionable odors and harmful effluents are not entering the surrounding environment.

A recent study on composting of solid wastes in the United States provides information on engineering, chemical, microbiological and environmental aspects of properly managed windrow and enclosed high-rate digestion composting plants.[17] Monitoring of temperature, moisture and aeration of the material in windrows and digestion tanks is essential for process control and for determination that conditions suitable for destruction of pathogens are being maintained.

Agricultural crop and animal wastes also cause solid waste problems which may require surveillance. A major pollution problem of this type is the result of high density rearing and maintenance of animals in the meat producing, dairy and poultry industries. Stored manures from these industries can produce substantial nitrite and nitrate pollution to ground and run-off waters.[18] Furthermore, Salmonella typhimumium and other diseases common to animals and man are capable of surviving current animal manure disposal procedures and therefore must be considered for further research studies and for possible future monitoring.[19]

SUMMARY

Pollution from solid waste differs from air and water pollution in that it tends to be more of a local problem. Major environmental effects are caused indirectly by decomposition products rather than the wastes themselves. Sensing techniques are the same or similar to those used in the air and water programs because the pollution caused by solid wastes is primarily from gases, liquids and particulates that enter the air and water for transport. Typical examples are (1) stack effluents from an incinerator discharging particulate matter and noxious gases into the atmosphere and (2) leachates from landfills contaminating ground and surface waters. Toxic materials such as mercury, lead, selenium, pesticides and PCB are potential pollutants from solid wastes. Surveillance of other potential problem areas as recycling and composting plants, sludges and manures also may be necessary.

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TABLE I

SOLID WASTE INFORMATION NEEDS

Purpose	Types of Data Needed
Administration and Management	Planning information
	Waste quantities and characteristics
	Cost and performance data
	Environmental hazards
	Legislative information
	Trends
Research	Generation factors
	Characterization data
	Solid Waste systems
	Storage
	Collection
	Transportation
	Processing
	Recycling
	Disposal
	Design information
	Cost and performance data
	Environmental effects
Pollution Surveillance (Monitoring)	Waste location and composition
	Significant effluents from
	Landfills
	Incinerators
	Other solid waste systems

TABLE 2

COMPOSITION OF INITIAL LEACHATE* FROM MUNICIPAL SOLID WASTE

Component	Study A		Study B	
	Low	High	Low	High
pH	6.0	6.5	3.7	8.5
Hardness, $CaCO_3$	890	7,600	200	550
Alkalinity, $CaCO_3$	730	9,500		
Ca	240	2,330		
Mg	64	410		
Na	85	1,700	127	3,800
K	28	1,700		
Fe (total)	6.5	220	0.12	1,640
Ferrous iron	8.7#	8.7#		
Chloride	96	2,350	47	2,340
Sulfate	84	730	20	375
Phosphate	0.3	29	2.0	130
Organic-N	2.4	465	8.0	482
NH_4-N	0.22	480	2.1	177
BOD	21,700	30,300		
COD			809	50,715
Zn			0.03	129
Ni			0.15	0.81
Suspended solids			13	26,500

* Average composition, mg per liter of first 1.3 liters of leachate per cubic foot of a compacted, representative, municipal solid waste

# One determination

RADIOACTIVITY SENSING - A CURRENT REVIEW

Vernon E. Andrews
Environmental Protection Agency
Western Environmental Research Laboratory
Las Vegas, Nevada

INTRODUCTION

The monitoring of radioactive environmental pollutants is based on the special characteristics of radioactive materials. Because of the variety of radioactive elements all facets of the environment are subject to radioactive pollution and may require various degrees of surveillance. As a result of several decades of development of equipment for detecting and measuring radioactivity, a wide range of systems of high sensitivity is now available. Although no single paper can provide a comprehensive discussion of all radiation measuring equipment and techniques, this review surveys those of interest to EPA programs.

BASIS OF RADIOACTIVITY SENSING

Radioactive materials provide the source of their own detection and measurement. Radioactive decay normally occurs by the emission of charged particles - alpha and beta particles. The decay of some isotopes is accompanied by gamma rays. The three types of radioactive emissions are physically different, and although most radiation detectors can be made to detect or measure all three, specialized systems and techniques are generally applied to each type. This specialization tends to increase the amount of equipment required for complete environmental surveillance; however, it also serves as a means of differentiating between the types of radioactivity.

Three basic types of radiation detectors - photographic film, gas counters, and scintillation detectors - have been in existence since the early days of radiation experimentation. Two relatively new developments - solid state detectors and thermo-luminescent dosimeters (TLD) - have had profound effects on radioactivity measurements.

Photographic emulsions are used for detection and quantitation of all types of radioactivity. Autoradiographs of environmental samples are used to locate and quantitate alpha and beta emitting particles. Of major interest in this discussion, is film dosimetry. Film packets, or film badges, are used to measure personnel or area exposures to gamma, and occasionally beta, radiation. The direct physical action of radiation on the film results in a darkening which provides an easily calibrated, reproducible measure of the amount of radiation to which the film was exposed.

Three families of gas detectors are widely used. Ionization chambers measure the ionization of gas molecules in the detector. The chambers are commonly filled with air at atmospheric pressure or argon under a pressure of several atmospheres. Radiation exposure is defined as the amount of ionization produced in air. The ionization chamber instrument, therefore, provides a true measure of gamma exposure.

A second form of gas detector is the proportional counter. Rather than measuring the ionization produced, the proportional counter measures the number of ionizing events occurring within the chamber volume. The signal produced by each event is proportional to the amount of ionization produced by each event, which in turn is proportional to the energy of the event for alpha and beta particles. Proportional counters generally exhibit low sensitivity to gamma radiation. By adjusting gas ionization amplification and discrimination on the signal produced, proportional counters can be made specific for alpha or beta radiation.

Geiger counter systems, employing a Geiger-Mueller tube detector, produce a signal pulse for all ionizing events occurring within the detector volume. Gas amplification is adjusted so that the output signal is the same for all ionizing events. This detector is used most widely as a gamma detector, although it will detect any ionization occurring within the chamber. Certain Geiger counters are used as beta counters.

Scintillating materials are widely employed as radiation measuring devices. These materials have the property of emitting light in amounts proportional to the energy of the radiation particle or ray absorbed within them. In various forms, they are used to detect and quantitate all forms of nuclear radiation.

One of the earliest radiation detectors was a ZnS screen which scintillates when struck by an alpha particle. Since the ZnS phosphor is very sensitive and is specific for alpha radiation it is still widely employed as an alpha counter.

Inorganic crystals of metal-halide salts activated with small amounts of impurities are widely used as extremely sensitive radiation detectors. The two most widely used inorganic crystal scintillators are NaI(Tl) and CsI (Tl). By varying physical dimensions of the crystals they can be made more or less sensitive to gamma radiation. Very thin detectors are insensitive to gamma radiation, but very sensitive to beta radiation. Scintillating crystals are used as gross radioactivity detectors and to measure the energy of individual radiation events.

Organic crystal scintillators, the most popular of which is anthracene, serve the same general purposes as inorganic scintillating crystals. Their special characteristics such as non-hygroscopicity, physical durability, and relatively low cost make them attractive for many applications in radiation measuring even though they are inherently less sensitive than inorganic scintillators.

Several liquids also have the property of scintillating upon absorbing radiation. These liquids are especially suited for measuring low levels of beta radioactivity in specially prepared samples. Mixing the sample with the scintillator allows for a detection efficiency approaching 100 per cent. In addition, the proportional response to radiation energy permits some discrimination on the signal allowing the simultaneous counting of two or more isotopes which have differing beta energies.

A hybrid scintillation detector is the plastic scintillator. These detectors use essentially the same scintillating compounds used in liquid scintillators. However, the scintillating medium is mixed with a clear plastic which is cast as a solid. Plastic scintillators are less dense and contain a smaller fraction of scintillating material than crystal scintillators, thus have a lower efficiency. This low efficiency is improved somewhat in some plastic scintillators in which lead is incorporated to increase density. Plastic scintillators are insensitive to physical and thermal shock, are non-hygroscopic, and are relatively inexpensive. Their primary advantage lies in their machinability. They can be cast and machined in a variety of shapes for unique and special applications.

The advances in electronics during the past decade have resulted in a family of radiation detectors known as solid-state devices. These detectors, such as lithium-drifted germanium diodes are used for measuring all three types of radiation. Their main advantage is extremely high resolution of radiation energies. This provides an excellent method of spectroscopy - or radiation energy identification - of alpha and gamma radiation.

Another recent development in detectors employes the principle of thermoluminescence. Electrons in the crystal matrix of the TLD are displaced by the energy of radiation absorbed in the TLD. Upon heating the TLD, the electrons return to their lower energy levels, emitting light in the process. The light is proportional to the absorbed radiation. Because of their high sensitivity TLD's are replacing film in many dosimetry applications.

UNITS OF RADIOACTIVITY MEASUREMENT

Because of the differing physical characteristics of nuclear radiation, two basic modes of expressing quantities are used in surveillance. The first mode, which corresponds to that used in relation to toxic pollutants, expresses the rate of radioactive decay relative to the unit volume or mass of the medium of interest.

Because of the amounts of radioactivity generally encountered in the environment, concentrations are most commonly expressed as picocuries (2.22 alpha or beta disintegrations per minute) per unit mass or volume. These concentrations are generally determined from laboratory analysis of samples; however, some media can be monitored for the concentration of some radionuclides on a real-time basis. In some cases the alpha and beta particles are counted directly. In others the gamma rays are counted and are related by their known abundance to the alpha or beta decay rate.

In addition to the potential for internal exposure to radiation via inhalation or ingestion, external radiation exposure can occur at a distance from radioactive materials due to the range of emitted beta particles and gamma rays. Radiation exposure rates are defined in terms of the ionization produced in air by gamma or x-radiation. The unit of exposure is the Roentgen. Absorbed doses in tissue are expressed in terms of rads and are used for all types of radioactivity. Absorbed doses, in rads, are essentially equal to exposure in Roentgens for gamma radiation. Because of its penetrating nature, external gamma radiation results in a whole body exposure, whereas beta radiation delivers a radiation dose only to the skin or surface of the eye. Portable radiation survey devices measure gamma exposure rates in Roentgens per hour or, integrated exposures in Roentgens. Some also have the ability to detect beta radiation, but the indications only provide a measure of relative intensity.

Environmental sampling for radioactivity involves all media – air, liquids, and solids. Air sampling requires collecting three sample types: particulates, reactive gases, and inert gases. The same sampling techniques used for other airborne particulates are applied to sampling for radioactive particulates. Depending on the analytical techniques to be used, the filter media may be varied. Since alpha and beta counting are routine techniques, a prime consideration is in using a filter medium which exhibits surface collection characteristics as opposed to depth-type filters. Commonly used filters are glass fiber and organic membranes.

Both portable and stationary samplers are available to collect samples over any desired period of time. In addition to collecting samples for laboratory analysis, some samplers provide an analysis of the samples during or immediately after collection. In one type, a moving filter tape collects particulates for a pre-set period of time after which the collecting surface is moved to an adjacent radiation counter for counting while a new sample is being collected. In another type a Geiger counter-detector is mounted adjacent to the filter surface and measures the collected particulate radioactivity. A unique sampler for monitoring the airborne concentration of radon daughters uses a washer-shaped thermoluminescent dosimeter (TLD) mounted near a membrane filter. Shielded against outside radiation, the TLD exposure provides a measure of the airborne radon daughter concentration.

Reactive gases are efficiently collected on activated charcoal. These gases, primarily radioiodines, are measured by their emitted gamma rays; therefore, collection in a depth medium does not detract from the analysis. The activated charcoal may be in the form of beds or cartridges inserted in a sampler secondary to a filter, or may be incorporated into the filter medium.

Inert gases are monitored in several ways which are unique to radioactive sampling. A basic technique which has wide application is the collection of compressed samples of air which are returned to the laboratory for direct counting or for separation and counting of the gas of interest. These samples may be either short-term grab samples or long-term integrated samples covering periods of up to a week. A method employed at the Western Environmental Research Laboratory is cryogenic sampling. Air is drawn through a bed of molecular sieve at slightly above liquid nitrogen temperature. Noble gases trapped on the sieve are removed and analyzed in the laboratory.

Sampling of milk, water and food is the same as for other pollutants. The analyses vary, depending on the radionuclides of interest and their concentrations. Soil sampling is conducted in many surveillance programs. In all cases the analysis is performed in the laboratory, often by radiochemistry. No standard sampling techniques exist for soil. Results are expressed as picocuries per unit mass of soil or curies per unit area, usually square miles or square kilometers.

RADIOACTIVITY MONITORING

Probably the widest variety of systems exists in radiation monitors. Most monitors can be defined as in situ monitors. Monitoring, or measuring of external exposures or exposure rates, is generally conducted near the source of radiation. Monitoring of external exposure rates is conducted with survey meters employing Geiger counter, ionization chamber, and scintillation detectors. The most widely used are Geiger counter survey meters. They usually respond to levels of radioactivity down to the background level and operate to several Roentgens per hour. The probes are shielded to permit measurement of gamma radiation only. A sliding shield can be opened to permit detection of beta radiations also. Accuracy of the exposure rate measurement depends on the comparability of the average gamma energy being monitored to the average gamma energy of the calibration source. A common calibration source is cesium-137. The 0.66 MeV energy gamma approximates the average energy of mixed fission products.

Ionization chamber survey meters in common use are generally applied in situations where the exposure rates vary from several milliroentgens per hour to tens or hundreds of Roentgens per hour. Ionization chamber designs using pressurized argon chambers respond to below-normal background ranges. Large volume ionization chambers, such as the Shonka chamber provide accurate measures of exposure rates at background levels, but are sensitive to environmental changes. They serve as research devices, or to compare to exposure rate measurements made by other sensitive survey methods.

Scintillation survey meters using small NaI (Tl) crystal detectors provide extreme sensitivity at background levels. Accuracy is very dependent on gamma energies. Because of the required detector packaging they detect gamma radiation only. Large scintillation detectors are used at the WERL in aircraft for locating and tracking radioactive plumes. These large detectors are also used in vehicles to survey large areas on the ground while mobile on highways and streets.

Several types of integrating radiation monitors or dosimeters are used for in situ monitoring. Film badges are the most widely used at the present time. Their low cost makes them attractive for continuous large scale monitoring. Film badges are unable to measure environmental background levels of radiation, but are relatively accurate at exposure levels above 30 milliroentgens exposure. TLD's are replacing film badges in many areas because of their ability to measure exposures from one milliroentgen or less to several Roentgens. Various types of TLD's are available, including powder, chips and enclosed types with the medium baked on a heating coil to facilitate readout. Although the initial cost is high, the TLD's in use provide long service and do not require the processing facilities needed for film processing. Another type of dosimeter is the personal pocket dosimeter. An electrical charge applied to a small galvanometer is dissipated in a radiation field. In self-reading types the accumulated exposure is visible on an internal scale. Others require a reader to observe the exposure. These types of dosimeters are used mainly in industrial application.

Remote radiation monitoring falls into two classes, (1) telemetry from a detector at the source of radiation to a receiver and readout at some remote location, and (2) measurement of gamma radiation at a location some distance from the source of the radioactivity. Although not in wide use, the latter technique has some important applications to environmental surveillance. Specially designed systems, such as the EG&G Airborne Radiation Monitoring System measure ground levels of radioactivity from an aircraft at approximately 500 feet above the surface. This allows rapid monitoring of large areas in a short time.

The detectors are large NaI (Tl) crystals with an automatic subtraction of background cosmic radiation and correction for altitude. Portable systems have at times been available to do a similar job, but with much lower sensitivity.

Hard-wired remote systems, employing any form of radiation detector, are used in a number of industrial applications. These systems can be connected to meters, recorders, or alarms.

Radio-telemetry of radiation monitoring data is limited in application. At the WERL, a radio-telemetry system using a Geiger counter detector is dropped by parachute from an aircraft flying above a radioactive cloud. The radiation data is radioed to the aircraft where it is displayed on a strip chart recorder in real time as the parachute is descending. These systems can also be dropped into areas inaccessible to mobile monitors to obtain ground level telemetered radiation exposure rate measurements.

Directional radiation detectors, sometimes referred to as gamma telescopes, are used in both ground and aerial applications of remote monitoring. Sensitive radiation detectors, usually scintillators, are shielded or collimated so that only radiation from a preselected sector can enter the detector. These are used to locate an airborne radioactive cloud relative to the detector.

DATA MANAGEMENT FOR MONITORING PESTICIDES AND RELATED COMPOUNDS

G. B. Wiersma and H. Tai
Office of Pesticide Programs
Environmental Protection Agency
Washington, D. C.

When first told that we were to talk on "Sensor Data Management", we immediately thought in terms of computers. As we gave more thought to the subject, the idea of talking strictly about computers seemed to only cover part of the problem. When talking about data management, we are really talking about management of the entire flow of information within a monitoring system. That is from the time it is collected in the field to the time that it is either published in open literature or presented to administrative personnel for action and consideration. It is this approach that we would like to discuss today. We will try to keep the principles and concepts in a general frame of reference, but, where necessary, we will illustrate with examples from our own experiences.

At a previous meeting in Las Vegas, the definition of monitoring was discussed. Out of that discussion came two ideas. One was monitoring for enforcement and the other was ambient monitoring. Ambient monitoring is conducted to determine background levels, to identify amounts present in a media and to determine trends through time. It is this type of monitoring that we will limit our discussion to today.

In a successful and well managed monitoring system the first phase is the planning and the collection of raw data from the field. Certain basic principles are involved in data collection. First, the objectives must be defined clearly. Precisely what are you monitoring for? For example, in pesticides, we define what pesticides, chemical contaminates and heavy metal residues are of interest. Another fundamental objective is what are you trying to do with the data? The National Pesticide Monitoring Panel wrestled with this subject for a good deal of time. They came to the conclusion that, in pesticide monitoring, the fundamental objectives should be to determine the presence, levels and changes in time of pesticide residues in a media. Other monitoring systems will have different objectives, but these must be defined prior to implementation in the field. (1)

Second, you must define your sampling population. You cannot send a field team out with just the objective of simply collecting environmental information or samples. They have to be told precisely what kind of samples to collect, where to collect them and how to collect them. In addition, so that your data will make some kind of sense, a certain amount of homogeneity has to be established about the sampling population. For example, to facilitate data organization and analysis in monitoring of soils for pesticides, the United States was divided into two general categories, cropland and noncropland. (2)

The third principle of data collection is to employ a sound, statistically based sampling design. This is of critical importance, particularly if some estimate is required on the reliability of your data about the occurance, the amount and the change through time of the pollutants detected.

The fourth principle is to maintain consistency in collection of samples. They should be collected using the same techniques and procedures at each site. This requires that the people handling your data collection be properly trained in the correct procedures and maintain sufficient caution to eliminate the possibility of cross contamination of the samples. Once the sample has been collected in the field, it should be sent, as rapidly as possible, to the laboratory. Care should be taken to insure that the samples arrive in a condition closely approximating their natural state. Once a sampling team is in the field, they should obtain as much information as possible about the site while there. In our monitoring program, in addition to soil and crop samples, the inspectors collect the following information on:

1. The crops that are grown on the sampling area.
2. How much irrigation was used and how many inches of water were involved.

3. The pesticide or fertilizer used in the year of sampling. This includes the amount applied, the crop it was applied to, what it was used for, its formulation and method of application.

This information has been invaluable in the evaluation and interpretation of information generated by our monitoring studies.

Once the samples have been properly collected and sent to the laboratory, the second phase of data management begins. This is the extraction and analysis of the raw environmental samples to determine contaminant levels. In our case, these include pesticides, heavy metals, PCB's and other chemical contaminants.

When we look at the general principles of the analytical technology of the pesticide residues, the important ones are the sensitivity and the selectivity of the method. The general trend has been to develop analytical methods specific for a particular pesticide or a particular group of pesticides, and sensitive to a level of 0.1 ppm, or even down to 0.1 ppb. The basic operations of the analytical procedures are (a) subsampling in the analytical laboratory; (b) separation of the residues from the sample matrix, or extraction; (c) removal of interfering substances or clean-up; and (d) identification and determination of the residue. In case the identity of the pesticide to be analyzed is not known in advance, the confirmation procedure may become a distinct operation all by itself. This operation can be elaborate and costly, in terms of both the manpower and the analytical equipment required for the identification of a component at a concentration of 1.0 ppm.

Specific chemical reaction and spectrophotometry were, in the early days, the principal analytical methods of identifying pesticides. As both the type and the use of pesticides have grown more and more complicated, the development of analytical methodology has inevitably evolved around a technique known as chromatography, a separation technique by which a multi-component mixture, passing through a separating medium, can be divided into individual components according to, generally speaking, their molecular weight, size or structure.

Column chromatography which generally refers to separation of liquid or dissolved substances has been particularly useful in the clean-up steps.

Gas chromatography, which deals with the separation of volatile compounds, has been developed as the mainstay of the pesticide analytical procedures. Due to the availability of a specific and sensitive detecting system, most, if not all, the recent "multi-detection" or "multi-residue" analyses have utilized gas chromatography.

The essential analytical procedures described are as follows:

1. Extraction: The first step in preparing a sample is to extract the pesticide residue from the material. Since no single solvent can dissolve or extract all known pesticides, the selection of solvent will naturally depend upon the type of pesticides and the matrix material. A great variety of solvents or mixed solvents have been used. The most common ones are pure normal hexane, or normal hexane mixed with isopropanol, acetonitrile, acetone, ether or methylene chloride. The methods of extraction include shaking, rotating, or the use of an extractor, such as Soxhlet extractor.
2. Clean-up: This is a step of separating the pesticide residues from the bulk of co-extracted materials. Two basic techniques are commonly applied:
    a. Partition - The extract is further extracted with an immiscible solvent. Ideal separation would be that the pesticides go into one layer while all other materials remain in another layer. The knowledge on the solubility of pesticides in various solvents, and its partition coefficient, or p-value, between solvents is of prime importance for a successful and quantitative partition.

b. Column chromatography - Some materials, especially lipids, peptides, fats and oils, have similar solubility as pesticides, and are difficult to be separated by partition only. The so-called "column clean-up" has become the essential step in handling biological samples.

The extract, or the partitioned extract, is introduced onto a column containing a separating medium, then eluted with a solvent, pure or mixed. The most commonly used column material is made up of mixture of magnesium and silicon oxides. The eluate is then concentrated to a definite volume, and ready for the final step; i.e., qualitative or quantitative analysis.

3. Separation and determination of pesticides. More often than not, the extract contains a group of pesticides and their decomposition products. All forms of chromatography, including paper, thin-layer and gas, have been used for this final stage of analysis. Among these chromatographic techniques, gas-liquid partition chromatography (GLC), or gas chromatography (GC), has been the most widely applied. Extensive research has been carried out on its application to quantitative analysis, especially in the field on the specific detectors.

A detailed discussion on gas chromatography is beyond the scope of this presentation. However, two fundamental operating parameters are briefly described as follows:

a. Column materials usually have a thermally stable compound, the stationary phase, coated on an inert material, the support. The most commonly used stationary phases are (a) polysiloxanes such as DC-200, SE-52, OV-17 or its fluorinated derivatives such as QF-1; (b) polyethylene glycol polymer such as Carbowax 20M, or (c) hydrocarbons, such as Apiezon. The support materials are usually diatomaceous earth, fire brick powder, Teflon or glass beads.

b. Detectors most frequently used include:
   1. Microcoulometric detector - for halogen-containing or nitrogen-containing compounds.
   2. Electron capture detector - for compounds containing electronegative atoms, especially chlorine.
   3. Alkali-metal modified flame ionization detector-for selective detection such as phosphorus
   4. Flame photometric detector - for selective detection such as phosphorus or sulfur.

The complexity of pesticides, i.e., the type, the use, the matrix and the reaction and decomposition, has been a challenge to analytical technology in both qualitative and quantitative analysis. While the exact application of general analytical principle varies with specific circumstance, the accuracy, or the authenticity of analytical results of a certain procedure has been of great concern to the users. Collaborative study to establish the validity has been the practice. The general trend in the pesticide analysis is the development of well-defined analytical manuals as an authoritative guidance. Agencies such as FDA(3), Water Quality Office (4), Perrine Laboratory of EPA (5) and Food and Drug Directorate of Canada (6) have published comprehensive texts on pesticides analysis.

In the laboratory it is necessary to maximize information obtained from each sample. In our case, we try to analyze each sample for as many pesticide classes, chemical compounds and heavy metals as practical. This requires that we schedule our chemical analysis and the flow of samples through the laboratory to take advantage of the different degradation rates among pesticides and chemical compounds. Those most likely to degrade rapidly in storage will be analyzed first.

We maintain a sample library. Whether this would be practical for all media and monitoring programs is debatable. Since we collect primarily soil and crop samples, it is a highly valuable and important part of our operation.

After the data has been collected and chemically analyzed, the raw data is transferred to a central staff. Their responsibility is to analyze and interpret the data so that it is useful to decision makers and others. This is the third phase of data management. The first principle governing data analysis is the function and structure of the central staff. It is important that this staff originally plans and manages the flow of information from the field to the laboratory. Naturally an effective system requires extremely close coordination and liaison between the laboratory staff, the field personnel and the planning and analysis staff. This staff should consist of people who have expertise in the areas of primary concern, as well as sound ecological training.

A second principle of data analysis is, do not attempt to extract more from the data than was set forth in the original objectives. I believe that many monitoring programs fall short at this point. It is critical that we maximize information from a sample collected in the field, but, in attempting to do this, we should never attempt to draw conclusions and inferences from our data that are not justified by the original sampling objectives and designs.

A third principle of data analysis is the proper use of computer support. We would say the critical first step is that there is a careful edit of raw data sheets by not only a technician but, where appropriate, by professionals. We have found that several man days of professional level review have paid off in a reduction of errors and an increase in the confidence we place on our information. When establishing a computer support program, it is necessary to make certain that the program, as established, is flexible and responsive to changes that are bound to occur in future handling of the data. We allowed the programmers to develop their techniques with a minimum of interference. To aid in the development of a viable program, we kept the analysis of data as simple as possible and still be consistent with our stated objectives. We minimized the addition of new ideas and the institution of too many changes. The only changes we initiated during the developmental stage were those that could not be instituted after completion of the program. When our program was completed, we tended to initiate changes and additions cautiously, finding that many times ideas that seemed pertinent at the time were not quite as valuable several weeks later.

May we point out the value of the programmable calculator. These machines are, in practically every sense a desk top computer unit. We use our's for mathematical and statistical analyses. This has saved us a great deal of time in analyzing data. As an example, a regression analysis at the computer center would take two weeks including data preparation, key punching and analysis. This same amount of data was analyzed using a programmable calculator in less than an hours time. The presence of such a strong analytical tool, readily available, allows you to conduct data analyses in great depth because it frees you from the time consuming and monotonous calculations required on machines of lesser capacity.

A fourth principle of data analysis is the proper application of statistical analyses to the data. Statistical analysis actually begins when planning field studies. That is the implementation of a statistically sound sampling plan, and it is the foundation of all future data analyses.

The next step in statistical analysis is to define the distribution form of your data. In pesticide residue data, the normal distribution is not appropriate because we have found the data to be severely skewed to the right. This can be somewhat alleviated by transforming the pesticide residues to logarithms. Tests have shown that while this transformation does not truly meet all the requirements of the normal distribution, it is close enough, and we have used it in lieu of better transformation.

A second problem in pesticide analysis is what to do with zeros. Somewhere between 25% and 75% of the data collected in the field either has pesticide or contaminant residues below the detectable limits of our chemical assays or else residues are truly absent from the sample. In environmental monitoring work a miss is as important as a hit. How are these zeros to be considered in the analysis of data? Unfortunately, we have not had the same success in handling the zero problem as we have had with transforming the distributions. One technique we have used is to determine the frequency distribution for a particular land area, either a biome, state or group of states, and calculate this frequency distribution either using probit analysis or a transformation involving standard deviates. This type of analysis has provided us with a good picture of the distribution of a pesticide residue through a medium, and it has allowed us to place confidence intervals about the levels we have detected.

Despite the obvious use of statistics in data handling, sometimes the best method is simply to forego any statistical analysis.

In the fifth principle of data analysis it is necessary to attempt, wherever possible, to coorelate the monitoring data collected in one system with that data collected in other systems. This correlation will begin with the central operational staff mentioned earlier, but the more sophisticated correlation of this data should probably take place at a higher echelon. In EPA, for all monitoring data, this would most logically be conducted by the Office of Monitoring.

All this effort is worthless if the information is not put into a usable form and presented both to the administrators and decision makers within the organization. In addition, it should be published in open literature so that other segments of the public interested in the results and needing the information can have it in a reasonable length of time.

Up to now we have been talking about sensor data management for present systems and most of these, at least for pesticides, do not utilize remote sensing techniques. What are the potentials for remote sensing of pesticides? How will they influence existing monitoring networks? In the short time remaining, we would like to consider remote sensing for pesticides, the techniques and possibilities..

A review of the literature reveals that remote sensing techniques have been applied to detecting a wide variety of environmental parameters. Anuta and MacDonald (7) used multi-spectral photography taken from satellites to identify soil, salt flats and water surfaces. Peake (8) used microwave radiometry to detect soil moisture levels in the upper 2-3 meters of the soil. A variety of techniques are being tested for the remote sensing of various pollutants in the air. Some include using shifts in sound frequencies (Doppler effects) to measure wind profiles in the boundary layer (9). Another technique is to use optical correlation methods to identify certain gaseous pollutants (10) and Leonard has reported on the use of Raman Spectroscopy to identify NO and SO_2 but with limited success (11).

Burgess and James (12) used aerial photographs to trace pulp mill effluents in marine waters and claimed success. Fisher (13) reported mixed results when trying to identify pollution zones in estuaries using infrared Ektachrome color film with a dark red filter and Kodachrome X with a UV filter. Microwave radiometry has been tested for possible use in identifying oil slicks in bad weather or at night (14).

The cited references are hardly an exhaustive review of the literature, but are given as examples of current attempts to utilize remote sensing techniques to monitor environmental parameters.

None of the above studies were conducted to determine the feasibility of identifying pesticide residues using remote sensing. To do so using present techniques would certainly be stretching the state-of-the-art. However, we are encouraged by the possibilities inherent in present remote sensing techniques that could make remote sensing of pesticide residues a reality within the relatively near future. One area of particular promise is the use of induced luminescence using UV and visible lasers. Gross and Hyatt (15) reported on the use of laser beams to identify a wide variety of surface materials. The concept basically is that the laser beams induce momentary luminescence in a material and that different materials have different signatures which are detectable at very low levels. Using this method they were able to obtain characteristic signatures for a variety of surfaces including Teflon, epoxy, light and dark phenolic surfaces, a variety of different kinds of leaves and certain minerals and oils. It is very speculative at this time to predict the usefulness of a method like this for identifying pesticide compounds. Certain basic research would have to be undertaken to test feasibility of this approach. They are as follows:

1. The relative merits of passive versus active sensing will have to be investigated. If active methods are used it will be necessary to determine what frequencies are most efficient for detecting pesticide residues.
2. Both the infrared and Raman Spectra for various pesticide compounds will have to be identified and selections made of the characteristic identifying bands.
3. The background spectrum data in natural environments will have to be studied and variations noted due to media, season, time of day, over head cover, etc.
4. The type of sensors best suited to detecting pesticide residues will have to be identified and developed.
5. Actual field tests will have to be made to test the procedures
6. In the beginning, remote sensing will have to be complimented by extensive ground-truth studies.

If we allow ourselves to dream, it is exciting to picture an effective satellite based remote monitoring system for a wide range of pesticide residues. This same system could also be easily adapted to identifying other chemical contaminants and possibly heavy metal residues. The results from the satellite could be telemetered back to a central processing point. This would be a virtually real time pesticide monitoring system. If properly managed, it would provide an instantaneous picture of pesticide residues in the environment.

When the time comes for setting up the data management system, we should be able to take advantage of those systems already in existence which are designed to handle other forms of remote sensing data. The basic principles of data handling will remain the same, but the mechanics of data handling will certainly be considerably different.

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PART II

E. Workshop Discussion Topics

WORKSHOP DISCUSSION TOPICS

WORKSHOP I - Sensor Monitoring Techniques

The following aspects of sensor and sensor-types are proposed for discussion for monitoring environmental pollution:

1. Current role of automated contact and non-contact sensors in EPA's established programs and what are problems preventing wider utilization of these sensors.
2. What future requirements are envisioned for automated contact and non-contact sensors.
3. A discussion of the use of sensors in monitoring enforcement.
4. A discussion of various contact and non-contact sensors now in use from the point of view of their applicability to point source monitoring and extended area monitoring.
5. A discussion of methods for and possible degree of automation in the acquisition of data.
6. Sensor technology utilized by other agencies for environmental application.

WORKSHOP II - Sensor Platforms

Sensor platforms suitable for identification and monitoring of environmental pollutants will be considered. Sensor platforms are to include all facilities from which either contact or non-contact measurements and data links may be deployed. As such, mobile or stationary sensor platforms may be established:

1. on or beneath the land surface;
2. on or within a water body;
3. on or beneath a sea bed;
4. in the atmosphere; or
5. in space.

Panel A will consider 1-3 above. Panel B will consider 4-5 above. Both panels will ask attendees to participate in discussions regarding:

1. Platforms now being utilized in the field at Regions and NERC's. It is expected that a list of platforms be constructed to match specific needs, i.e., in (2) above, delineate the use of small boats, barges, buoys, and submersibles. Future possibilities and capabilities should be similarly outlined.

2. Region, NERC and Headquarters representatives should identify platform types that could be used now and deemed desirable in the future, ignoring availability. Also identify the type of use, e.g., continuous monitoring or special short-term investigations for monitoring or enforcement purposes. Also identify relative needs in terms of large area or small area monitoring. Consider:

    a. aircraft for air, water and terrestrial surveillance or investigations, e.g. EPA aircraft, other government agency aircraft, private aircraft, commercial airlines, balloons and dropsondes;

    b. sea and inland watercraft, buoys, etc.;

    c. land platforms, e.g., vehicles, mobile labs and fixed stations;

    d. spacecraft (NASA representative may identify available and planned platforms).

3. Deployment should consider region and NERC needs in terms of

    a. do all (or specific) regional offices and NERC's need specific types of platforms available at their location, or can one or more NERC provide support to all Regions;

    b. reviewing factors affecting deployment, such as estimated use periods, costs of acquisition, maintenance and operational manpower requirements, support facilities such as shops, laboratories and vehicles, mobility and reaction times required.

4. Review platforms currently existing in other agencies. These may or may not be available to EPA on a cooperative or contract basis. Review past cooperative and contracted efforts for sensing programs with other agencies. Identify desirable cooperation that was sought but could not be obtained, or should be pursued.

WORKSHOP III - Sensor Data Management Workshop

Panel A - Current Data Systems Panel

The purpose of this panel is to uncover Regional needs for data management systems. Of necessity, current systems must be discussed and their advantages and shortcomings from the regional point of view indicated. The following areas are suggested as basic items for discussion:

(1) the utilization of current EPA data management systems by the Regional Offices;

(2) the response of the data systems to present needs. Do the systems provide all the outputs needed by Regional Offices, is the response timely, are the present systems easily querried, etc.;

(3) requirements on current systems to insure quality control and standardization. Is the data from state-of-the-art sensors treated in the same manner as wet chemical measurements? Is the data from all sources given equal weight, etc.;

(4) coordination of EPA data management with other Federal, State and municipal agencies. What is level of coordination, etc.

Panel - B - Future Data Management/Discussion Guide

1. A national/regional environmental data distribution infrastructure.

    a. Includes EPA and non-EPA monitoring capabilities;

    b. satellite systems (ERTS, GOES, EOS, etc.);

    c. ground based hardware (communication systems and computers);

    d. organizations relationships and responsibilities.

PART II

F. Workshop Panel Summaries

SENSOR MONITORING TECHNIQUES WORKSHOP

Panel A - Contact Sensor Techniques

Panel Chairman, D. Krawczyk, EPA

HISTORICALLY

The water program at the Federal level acquired or developed sensor systems to measure pollutants at site locations on rivers, lakes, and streams. The prototypes were tested on the Ohio River and produced data for measuring water quality. When these in situ sensors were developed, it was the aim of the program to produce equipment which would require a minimum amount of maintenance (once a week visit to a site by a technician to calibrate and check sensor for output).

The air program went to the instrument manufacturers and pointed out their needs for measuring constituents in ambient air. The proprietary instruments were produced to the needs and specifications of the air monitoring program to measure appropriate constituents in ambient air. These instruments were then made available through grants to state and local air monitoring agencies. The state and local monitoring systems would use the instrumentation to collect data and samples. The data and samples would then be sent to the appropriate Federal air laboratory for further analysis.

PRESENT ROLE

The panel and Bill Sayers in his talk provided input that the Federal water program has approximately 60 sites where in situ sensors measure dissolved oxygen, temperature, conductivity, pH, oxidation-reduction potential, chloride, turbidity, and solar radiation. There are a total of approximately 300 sites in various locations operated by federal, state, interstate, and local agencies that measure from 2 to 12 parameters. Of the 300, 89 are identified in the Chemical Engineering News articles of September 20, 1971, pages 16 through 20.

Dr. D. S. Barth, in his paper presented on November 30, 1971 at this workshop and re-emphasized in the panel discussion, pointed out the availability of instrumentation for measuring SO_2, oxidants (ozone), carbon monoxide, total hydrocarbons, NO_2-NO_x, and particulates. This instrumentation was placed on close proximity to air sampling devices and samples were manually transported from the sampling site to the laboratory for treatment and analysis.

The members of the panel pointed out that air pollution problems usually occur in high population density sites. These sites of necessity contain local laboratories (state local) where samples of air are collected and run daily. EPA (formerly the Air Program) provides monetary and technical support for these laboratories.

The Air Program has gathered field base line data at a variety of locations so that some normal ambient level can be established. Coupled with this on site response, the air network collects samples for submission to the air program laboratory for further analysis.

Computerization of data is a must in use of *in situ* measurements. The data is either put on tape and read into a computer, telemetered directly into a computer, or any combination of these systems to provide information. There are systems which compare water quality standards with in situ real time sensor data and flag violations. The very nature of water monitor sensor and air sampling location identify them as point source data collection systems.

A considerable amount of the panel's time was devoted to the use of data in the legal arena. It was pointed out that the data provided by the sensor's must be accurate and precise. The route of collaborative testing provides precision and establishes accuracy in the conformance to rigid specification of operation and maintenance and calibration It was the view of the chairman that *the establishment of precision, accuracy, and the reliability of the sensor* had been accomplished through the Analytical Quality Control Program in the water area under the auspices of the AQC Research Program. It was the view of Dr. A. P. Altshuller that the production of standard gases for calibration purposes and a Quality Control Program provide precise and accurate data.

All of the regions have at least one in situ water monitoring station and all large population areas have air monitoring stations (sensor in this case is the collection of sample and rapid analysis). The data that is collected is evaluated and summarized to invoke a response such as initiating action. The disclosing of air quality data is normally accomplished through daily notification in local newspapers and reported in the television and radio media usually as part of the weather report.

The regional people would like to see the production of suitable biological and microbiological in situ sensors which could alert the agency to the presense of a toxic waste situation or to a potential health hazard through bacterial contamination. The production of a rugged sensor which will function in gross pollution situations was also the desire of a number of panel participants.

The development of ion selective electrodes seems to hold some promise especially if it becomes essential that effluents be monitored. All in all, in the view of the chairman, the input and output of this panel was vigorous, stimulating, and in retrospect, hopefully productive.

What is really needed now is the establishment of appropriate lines of communication between the regional people and ORM when specific needs are identified to remotely measure a pollutant.

SENSOR MONITORING TECHNIQUES WORKSHOP

Panel B - Non-Contact Sensor Techniques

Panel Chairman, S. Verner, EPA

I think I can honestly say that the panel on non-contact sensor technology produced a full and frank discussion of problems associated with these instruments. The discussion, at times, spilled over to monitoring strategy with particular emphasis on remote sensing technology.

One of the first panelists to comment in this workshop pointed out, and very cogently I might add, that Sensor System requirements must be based on environmental standards, which are not only specific as to the pollutant and the level of pollution, but also indicate accepted techniques for sampling the pollutant. Wherever such standards exist, newer developed sensing techniques will have to be compared with these standards and at the very least perform equally as well as existing techniques in order to be widely adapted. Where standards do not yet exist it is difficult to imagine how sensors can be accepted into an operational monitoring program. At the same time, however, I think it is not unreasonable to expend effort in development of non-contact sensors - especially when prospects seem good for developing a particular sensing technique - even where standards do not yet exist. Since Dr. Altschuller described the other day how long it takes to develop and field test instruments, and with the anticipated rapid evolvement of new standards in the next year or two, we can confidently expect these new standards to be promulgated well before a new generation of sensors are ready for evaluation.

At this point one might ask, why do we need non-contact sensors; is it reasonable to justify the expenditure of large sums of hard-to-find money to develop these instruments? It was quickly pointed out by several of those present that the potential of non-contact sensors when employed in a remote sensing mode to cover large, even vast geographic areas in a relatively short time and to pinpoint environmental problems is so superior over other sensing techniques that it is indeed well worthwhile to expend these funds.

Non-contact sensors, particularly photographic techniques, are unrivalled in detecting the extent of haze and smog conditions, smoke-stack emissions, outfall and effluents discharged into rivers and lakes, up wellings, thermal pollution, algal blooms, sedimentation, etc.

Sid Whitley of NASA's MTF Facility discussed how a photograph of the earth taken in UV light showed a very distinct haze or cloud condition which was not discernable to the eye nor to any other photographic light wave band.

Other non-contact sensors, often based on electro-optical instrumentation involving correlation or matched filter techniques and derivative spectrometry, show great promise of detecting many atmospheric pollutants, particularly those whose resonance absorption lines lie in the near IR thermal region. There is a practical reason why the near thermal IR region is a cut-off for these instruments and that has to do with the sensitivity level of the detector. The best solid state detectors today such as Pb Se or Hg-Cd-Te can operate out to about 10m with no cooling or at most thermo-electric cooling. Without cryogenic cooling requirements, these instruments become much more practical.

A great many non-contact instruments have already been built which have qualitatively detected many atmospheric pollutants such as oxides of N, S, and C, as well as hydrocarbons, NH_3, etc. It is understood that North American Rockwell has built a second derivative spectrometer which has detected several impurities in water.

As important as qualitative detection of pollutants is, it is quantitative detection which is crucial to EPA. This is a considerably more difficult problem and at this time no one can say with certainty which of the non-contact sensors presently under development will meet this requirement. In addition to inherent limitations, a basic difficulty non-contact sensors must overcome is the fundamental problem of atmospheric interferences.

Several persons also noted that to justify their development expense, future non-contact sensors will have to be good; by this I presume they meant reliable, provide inexpensive data acquisition, operate under extreme ranges of temperature and humidity and other hostile ambient conditions, and yet maintain accurate calibration. And of course, a new instrument or technique would have to prove itself cost-effective before it could be introduced in monitoring systems.

One problem was highlighted during the discussion which I believe has an important bearing on all monitoring strategy, and is not exclusively that of non-contact sensors. The problem is one of knowing just where to collect environmental data and what the frequency of sampling should be - this point was also emphasized in one of the informal papers. Even with the best sensor conceivable, if it is not deployed properly the data obtained from it will have little value to EPA. Basically, the problem is that the kinetics of environmental dynamics is not too well understood. In the case of the atmosphere, it was pointed out that meteorological parameters effect our quality to a considerable extent and I think it was Dr. Bill Davis of NOAA who indicated that a study of millimeter radiometry of atmospheric temperature profiles would help considerably in understanding the dynamics of the atmosphere.

In attempting to get an idea of what development costs for non-contact sensors might be, reference was made to the ESSO report which projected five year development costs for atmospheric pollutant sensors and estimated these would be about 70 million dollars. Dr. Al Ellison averred that development costs for a single pollutant detector would be at least $200,000 and could easily be doubled or more. Someone stated that Barringer has a UV correlation spectrometer for SO_2 and NO_2 costing $20,000 per unit.

SENSOR PLATFORMS WORKSHOP

Panel A - Marine and Terrestrial

Panel Chairman, M. Felsher, EPA

The panel concluded that Regional and Laboratory needs in regards to sensor platforms do cover the entire range of such platforms as they are now available. The panel feels that all platforms are potentially useful. In the native environment this includes the proper use of boats to barges to buoys. It includes stationary, mobile, and towed platforms. It includes emplacement on the water surface, under the water surface, and on the subshale sea or estuary bottom.

The discussion of terrestrial platforms centered mainly on the use of mobile vans, as special event vehicles able to perform immediate and competent analyses on a trouble-shooting basis. Routine monitoring and complex analyses would be reserved for established regional and national laboratory centers.

The panel felt that the Agency should contact other governmental departments and seek cooperation in securing needed sensor platforms, such as boats and land vehicles.

Availability of suitable marine platforms will depend upon geographic necessity. Also, each Region should have enough mobile vans or special-event laboratories to assure the acquisition and analysis of sufficient data and dissemination of information of such quality as it required by our Agency mission.

SENSOR PLATFORMS WORKSHOP

Panel B - Aircraft and Spacecraft

Panel Chairman, L. Dunn, EPA

SPACECRAFT

The potential advantages of remote sensing from spacecraft include global synoptic coverage of oceans and continents with resolution necessary to disclose large-scale pollution effects. The ability of satellites to take sequential imagery of large areas over extended periods of time will be a very valuable tool. These attributes make satellite sensing particularly beneficial for monitoring in the following areas:

a) regional resource management (Forestry)
b) land use planning (sewage treatment, outfalls)
c) agricultural management (techniques)
d) documentation of long term environmental quality
e) large scale pollution effects

The primary sensors available on spacecraft are metric cameras multispectral line scanners and microwave and IR radiometers. The NASA ERTS and Skylab spacecraft have a number of sensors which can be useful for monitoring environmental quality such as above.

The disadvantage of satellite monitoring for environmental pollutants is that most of the data acquired from space relates to environmental quality, is a "cause-effect" type, and is not pollution specific. As a result, active or passive sensors that can qualitate and/or quantitate specific pollutants, with the exception of temperature, must be developed.

AIRCRAFT

Aircraft have the specific advantage of low altitude flight which enables the sensors to achieve greater spatial resolution. Another major advantage of aircraft is the ability to carry "in situ" sensors. Many "in situ" real-time air pollutant sensors have recently become available for monitoring. In most cases, these sensors are pollutant specific. Examples of these sensors are:

SO_2
Hg
NO_x
Ozone
CH_x
Piezo-electric (mass per unit volume)

The NASA Earth Resources Aircraft could provide some aerial coverage of environmental data. These aircraft include P-3A and C-130 medium altitude aircraft, and an RB-57 and U-2 high altitude aircraft. NOAA also is organizing an aircraft capability to respond to National emergencies which could also be of assistance.

RECOMMENDATIONS

The regional representatives expressed a desire for the following:

a) A listing of sensors (state of the art) which are presently available and which can be employed for environmental quality monitoring.

b) The majority of the regional representatives were concerned that the remote sensor data produced was of little value unless the data was analyzed. Their in-house expertise and funding to contract for these services were very limited.

c) Because of the resources shortage within the regions at the present time, the interpretive analysis capability should be developed immediately within EPA. Supplemental support should be arranged with existing facilities in other government agencies such as NASA, USGS, and NOAA, or from industry and universities as needed.

d) A list of sensors, aircraft, data interpretation assistance, and scheduling from the Federal Agencies should be documented and made available to the regional EPA offices as soon as possible.

e) There should be more coordination between EPA and other Federal agencies with specialized aircraft monitoring capabilities, such as NASA and NOAA.

f) EPA should investigate the applicability of the ERTS data in the areas mentioned and provide scientific investigators and monitors on select investigations concerned with environmental studies.

g) The use of satellites to provide a data relay capability such as that to be provided by the NASA Earth Resources Technology Satellite in the Spring of 1972 should be explored. Data transmission platforms should be obtained as soon as possible and disseminated to the regions who have a need and are capable of attaching the appropriate in situ sensors.

SENSOR DATA MANAGEMENT WORKSHOP

Panel A - Current Data Systems

Panel Chairman, J. Reagan, EPA

The Current Data Systems Panel discussed the existing data systems for current adequacies and deficiencies. Future development may be in part guided by eliminating current defects and problems. Although each regional office has need for good technical and management information systems, the discussion was limited to pollution source and environmental quality measurement systems.

Three separate areas were considered: data acquisition, data processing (including storage and retrieval), and data usage.

Data Acquisition

Many types of data acquisition equipment are available to data collectors. These range from simple analog trace devices in the hundred dollar range up to computerized acquisition, reduction and analysis systems costing in excess of $50,000.

The paper by Lathrop and Jones on the use of LSI data storage given at the Joint Conference on Sensing Environmental Pollutants discussed some of the existing systems and their drawbacks. Cost, usefulness and durability appear to be conflicting factors in current acquisition systems. Electromechanical paper tape punches, though cheap, tend to record erroneously or break down. Strip chart recorders may be inexpensive but inaccurate, or accurate and expensive, as contrasted by the Rustrak and Leeds-Northrup plotters. The authors point out that the power requirements for most recording systems shorten the possible unattended operating period using stored power. Their particular application of LSI data storage techniques to buoy thermal sensing is promising but is limited in data storage volume to 10^4 bits. This is a severe limitation for most sensors.

Sophisticated instrumentation is generally based upon inference procedures rather than direct measurement. Many of these instruments produce vast quantities of data which must be smoothed and compared to files of signatures for complete compound identification and quantification. These instruments should generally have dedicated mini-computer systems to enable the operator to rapidly acquire and evaluate data.

Multiple instrumentation facilities such as trailer mounted laboratories or monitoring facilities should have fairly sophisticated acquisition equipment mounted in them. Simple data translaters can serve in lieu of multipurpose digital computers when rapid data interpretation is needed. However, some instrumentation may require that data be manipulated in a complex manner, thereby requiring dedicated logic devices.

With a view to regional coordination, mobile platform facilities should be developed jointly to achieve some economy of scale and more importantly the interchangeability of parts and processes. Regional usage may fluctuate allowing the systems to be loaned between regions for short periods. Comparability is important to assure ease and accuracy of operation by all personnel.

Recommend that an exhaustive survey be made of available systems, outlining the capabilities of each and its limitations. Further research into data reduction techniques prior to recording should also be made. Definition of the output data required for the end user can allow consideration of the combination of data integration techniques with data storage and identification techniques to reduce resources alloted to data acquisition. The subsequent costs in computer processing and manpower must be considered in the light of total least cost and availability of the different resources. Investigation should also be made of the applicability of declassified communication and information system research.

Existing systems in EPA include STORET and NADIS with additional systems on oil and hazardous materials, radiation surveillance, pesticides in air, residual soil pesticides and human pesticide residues, solid wastes and probably others.

The STORET system is on an IBM 360/65 with data cell storage provided by Boeing Computer Services. Current operating experience is good compared to the recent past. Basic software problems have been solved leaving only hardware failures and operating mistakes as annoyances. Approximately 100 terminals are now online, based in water analysis, and use agencies around the country.

Data on physical and chemical measurements of water samples are in STORET. Also, inventories of industrial and municipal waste sources, implementation plan schedules and certain math modeling capacity are part of the system.

A change in contractors providing the supporting hardware was disastrous from the user's point-of-view. It is strongly recommended that the disruption in service of such a change be considered an added cost when comparing competing bids for the support service. In no case can this disruption reoccur.

The NADIS system is based on an EPA IBM 360/50 computer located at the Research Triangle Park, North Carolina facility. Transfer of the National Aerometric Data Bank from the Honeywell 400 in Cincinnati and alteration of the SAROAD programs to the new computer are in process. Concurrently, the past and current data are being collected from state and local agencies by the MITRE Corporation on contract to EPA.

Hardware limitations currently preclude the direct access of the data base by regional offices. With increasing volumes of data and data utilization requirements, direct access is deemed necessary in support of regional operations.

A new data base on oil and hazardous materials spills has been established with another contractor. Over 25 pieces of information can be stored to describe each occurrence. Few of the existing terminals can access the data base through the current system. The problem is due to the nonstandard data transmission modes of ASCII vs. BCD.

In addition, the Office of Radiation Programs is designing a data system for radiation data, Office of Solid Waste Programs is implementing both a data and monitoring system for solid wastes, and the Office of Pesticides has a data base on soil residues and is designing one for human tissue residues and air concentrations.

Recommend that the proliferation of data systems stop and that existing systems be coordinated. This coordination is important to facilitate correlative work that will be carried on. Accessibility should be improved along with operating details. Coordination with other agencies is vital. Contact should be established at the highest level with communication channels established at the operating level. These contacts should include NOAA for oceanographic and atmospheric data and NASA for ERTS and other programs. Technical Coordination Papers in eight areas including oil, ships, radiation, the Navy Environmental Protection Data Base and other are due to the Pentagon for review by mid December. The EPA should coordinate activities with the Navy in these common areas of interest.

Data Usage

Usage and manipulative capabilities in the Regional Offices are limited to the capabilities offered by programable calculators and some simple math modeling capability in the STORET system. The development of laboratory capabilities in the Regional Offices should be accompanied by the development of a data processing capability.

Data processing techniques are being centralized within the Management Division of most, if not all, Regional Offices. Coordination of Regional developments should be stressed to achieve interchange of techniques. The development of this capability is directly associated with the selection and acquisition of the data handling equipment for the entire agency.

Data Reliability

Both the air and water data bases have been characterized as very large sources of data of questionable reliability. Some data is very good, but some is terrible. Nonstandard and unequivalent sampling locations, frequencies, methods and procedures hamper the large scale integration of previous environmental measurements. Reliability judgements are largely subjective and may vary between persons. The development of standard, reliable methods is again restressed here as it has been in other conferences and panels.

SENSOR DATA MANAGEMENT WORKSHOP

Panel B - Future Data Systems

Panel Chairman, E. Grenning, EPA

BACKGROUND

It is helpful to establish a rational frame of reference within which a future environmental quality data management system must function effectively. Figure 1 presents a simple block diagram showing where the data management system fits in a conceptualization of the overall environmental monitoring operation.

Environmental quality data are acquired by various sensors (contact, non-contact, biological) transmitted, analyzed, stored and retrieved by the data management system which produces information needed by the four indicated functions, enforcement; state of environment; research and environmental planning. The four functions are not independent, research having some input to all of them and enforcement and planning providing a direct feedback to environmental quality. At any point in time the hardware and software configuration of the data management system will be determined by its interfaces with the overall monitoring operation, i.e., by the raw data acquired by the sensors and the information output required by each of the four functions.

As information requirements and sensor technology and concepts change with time the data management subsystem configuration will evolve in response to those needs and will, to some degree, influence the evolution of those needs. The initial configuration of the data management subsystem consists of all of the EPA and non-EPA environmental quality data management systems currently in operation.

FUTURE DATA MANAGEMENT SYSTEM

What kind of data management system configuration should be established? It was the consensus of the panel that a traditional pyramid type of infrastructure containing loca; state; regional and national levels would be appropriate. Figure 2 presents a simple schematic of this concept. Information flows upward in the infrastructure with environmental considerations and corresponding data requirements becoming increasingly synoptic in moving from the local to the national level.

Data could be acquired independently at each level and combined with data from the next lower level to obtain a needed measurement of environmental quality. For example, a region could independently contract for an aerial survey of its territory and use in-situ data obtained from the states for ground truth corroboration of remote sensing imagery.

Some doubt was expressed concerning the usefulness of environmental situation centers at the regional and national levels mostly because of the time lag between pollution detection by monitoring and correction through enforcement. However, a need for regional and national episode centers incorporating modern data management and display techniques aimed at monitoring and possibly controlling short lived environmental phenomena such as air pollution episodes, oil spills toxic substance releases, forest fires, etc., was recognized.

The practical impossibility of perpetual storage of all acquired data was recognized and possible criteria for data destruction discussed. In general the duration of storage of a particular datum is approximately porportional to the spatial or temporal scale of the phenomena the datum represents. Accordingly, a possible mode of data destruction starting with an hourly average of some parameter would be to regress to a daily average in the first year; daily to monthly the next year; monthly to semi-annually; semi-annually to annually and then annually to destruction.

This would result in stepwise data destruction while tending to maintain longer duration temporal averages germane to synoptic environmental considerations. Data representing some large spatial scale environmental phenomena might be stored perpetually, e.g., the annual average temperature of the earths atmosphere at sea level.

ESTABLISHMENT OF FUTURE DATA MANAGEMENT SYSTEM

It was agreed by the panel that the data, statistics and/or indicies required to best serve the purposes of the four information use functions indicated in Figure 1 must first be carefully defined since they will be a strong determinant of the data management system hardware and software configuration. Having specified information requirements a reasonable next step would be the combination of all existing EPA data management systems (e.g., STORET, NADIS, pesticides and radiation.) into a single comprehensive system capable of partially satisfying the information requirements. In parallel a survey of existing non-EPA environmental data management systems should be performed with all useful systems being appropriately incorporated into the overall data management system.

Any gaps in required information remaining after selective combination of existing systems should be filled by newly developed EPA monitoring and data management capability. It is anticipated that a substantial amount of executive subroutine software development will be required by these activities.

ORGANIZATION AND RESPONSIBILITIES

It was the opinion of the panel that EPA (Headquarters and Regions) should have exclusive overall data management responsibility for the national environmental monitoring system outlined above. EPA should also be responsible for operating the portion of the system consisting of existing EPA networks as well as networks placed in the field to fill gaps in the national monitoring system. Furthermore, there is monitoring being performed by other agencies that the panel believed should be properly conducted by EPA, e.g., the water quality monitoring conducted by the USGS on the basis of an agreement made with FWQA three years prior to the formation of EPA. However, there was also unanimous agreement that development of a national environmental monitoring system must be pursued in a cooperative rather than competitive spirit in spite of austere budgetary constraints.

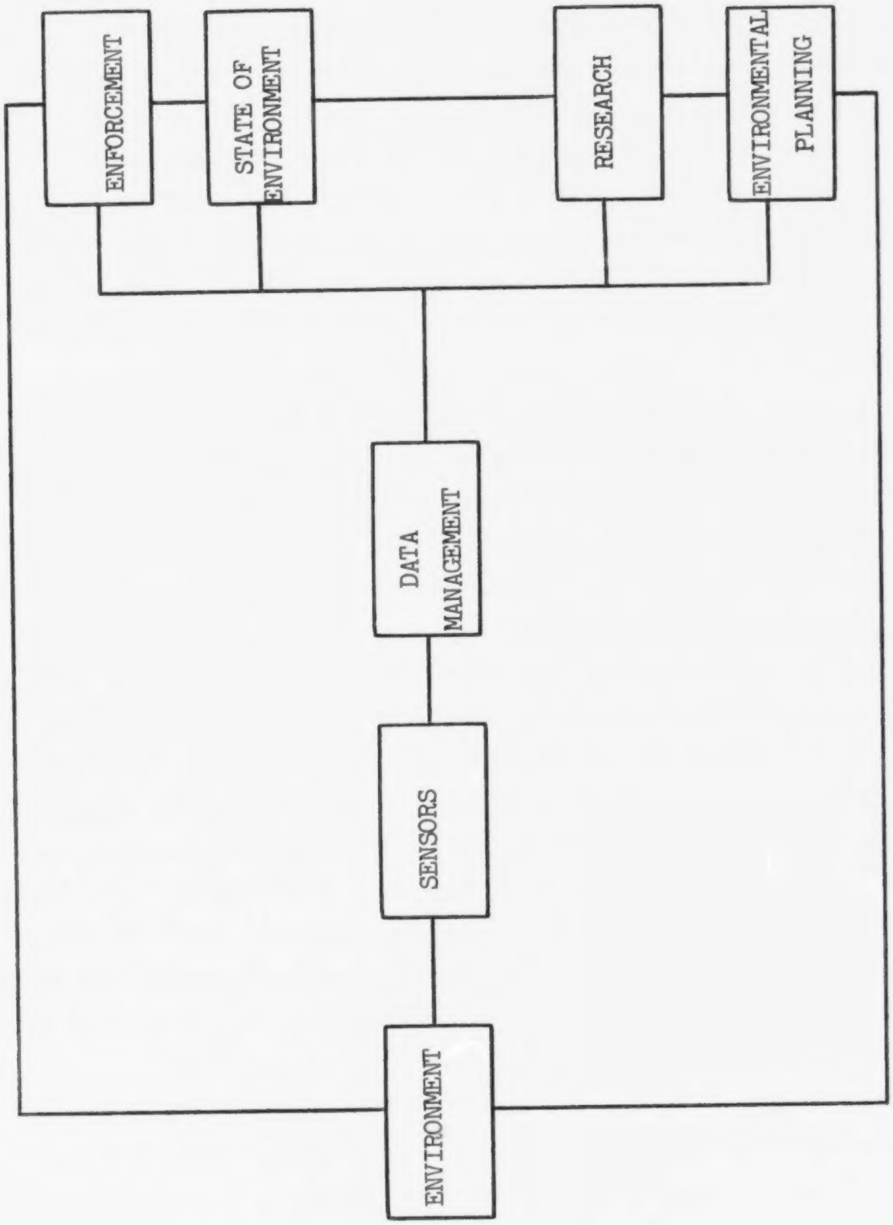
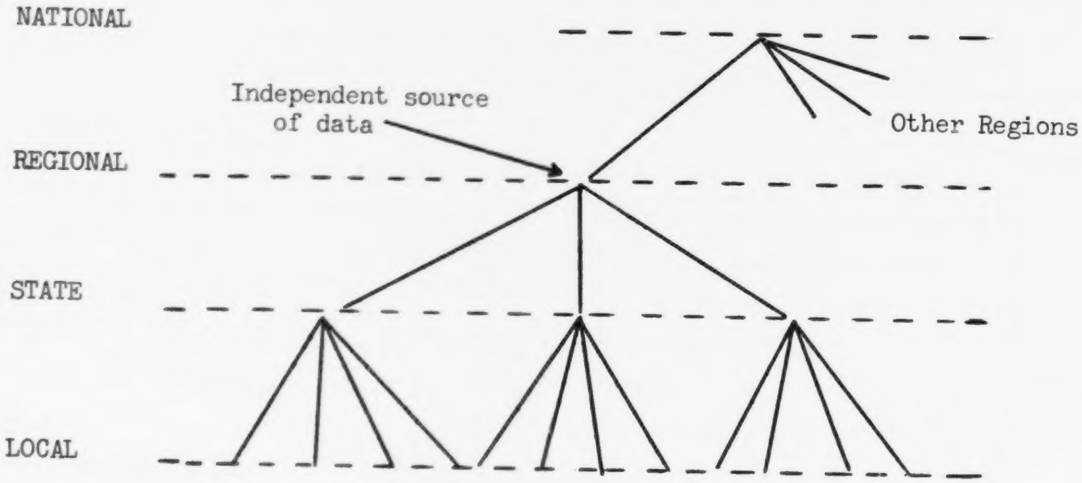

ENFORCEMENT
STATE OF ENVIRONMENT
RESEARCH
ENVIRONMENTAL PLANNING
DATA MANAGEMENT
SENSORS
ENVIRONMENT

FIGURE 1 MONITORING SYSTEM


NATIONAL
Independent source of data
Other Regions
REGIONAL
STATE
LOCAL

DATA MANAGEMENT INFRASTRUCTURE

FIGURE 2

SENSOR PRIORITIES WORKSHOP

Panel A - Short Term Panel (1-5 years)

Panel Chairman, C. Weber, EPA

Short term sensors, platforms and data management needs in each of the specific monitoring areas are as follows:

NOISE

Current sensors and platforms for measuring general ambient (background) noise are adequate. There is a need for a valid universal scale on which to express noise from all sources. Ways must be explored to measure the effects of noise on human welfare - such as the possible physical and psychological effects, and optimum noise levels. Methods must be developed to determine the public reaction to noise - such as personal interviews, and to collect and channel public complaints to a (central) office which can evaluate and act on the complaints.

AIR

The air pollutants of principle interest are SO_x, NO_x, OX, HC and particulates. No operational automatic field sensors are available for these pollutants but sensors for SO_x and NO_x are currently under evaluation and should be operational in the near future. Sensors should be developed for the other principal pollutants to monitor emissions and ambient air quality. Use of aircraft to provide real-time data on air quality should be given greater attention. As with noise, methods of measuring low grade effects on human health and welfare should be developed. More effort should be expended in shortening the time between sample collection, analysis and data evaluation.

WATER

This area has the largest number of operational "in situ" sensors available for field work. The parameters measured include temperature, conductivity, pH, dissolved oxygen, dissolved chlorides, oxidation-reduction potential and turbidity, listed in the order of their reliability. Non-contact remote measurement of surface temperature by IR-scanners is in an advanced stage of development, chlorophyll measurement by air or spaceborne spectrometry and laser activated fluorescence shows promise and should be perfected.

IN-SITU

Sensors are also under development for phenols and oxygen decay (oxygen demand). Ion or compound specific sensors should be developed for dissolved bound nitrogen, total phosphorus and other macronutrients and specific pollutants.

Fouling and other problems requiring frequent maintenance of in situ sensors are serious problems affecting the cost and reliability of the data; high priority should be given to the development of anti-fouling devices and increasing sensor reliability.

SOLID WASTE

Aircraft and space platforms should be used to determine land utilization for solid waste disposal, optimize waste disposal practices and determine geographical distribution of solid waste disposal burdens. Methods must be developed to quantify the solid waste burden on a national scale, and to provide real-time data on trends in the waste burden and chemical composition. Environmental effects of land fills - such as seepage of microbiological pollutants into ground and surface waters, and the effect of seepage and gaseous emissions on adjacent vegetation and annual life. Incinerator emissions should be monitored. Much of the technology developed or in use by the air and water pollution control programs is applicable to monitoring solid waste disposal activities.

PESTICIDES

Monitoring programs for pesticides in air, soil and water should be more closely coordinated, and completely integrated, if possible. Techniques for non-contact passive or active sensing of pesticides on the soil surface should be investigated, using UV or other appropriate regions of the EM spectrum. Efforts should be made to reduce the time between sample collection, analysis and data evaluation.

RADIOACTIVITY

Environmental levels of tritium and noble gases should be monitored. Current ambient levels of tritium activity are too low to measure "in situ" with present equipment, and methods of isotope enrichment should be developed.

GENERAL RECOMMENDATIONS

1. Level of monitoring activity in all areas should be substantially increased by allocation of additional funds and positions.
2. Need to present information on environmental quality to the public on a regular basis - to provide visibility for the monitoring program, increase public awareness of the program, make environmental data useful to the public, and gain additional legislative support.
3. Courses on sensor use in the EPA program should be included in the Agency Training Program.
4. The Agency needs a program of instrument certification to aid industry, state and local governments in acquiring instruments to meet effluent (emission) standards.
5. Telemetry of data from sensor platforms via stationary satellite to an EPA ground receiving station could reduce overall cost and increase efficiency of data collection by the central data handling system.
6. Methods of data reduction (integration) at the sensor platform should be developed to reduce the volume of data transmitted to the central data collection facility.
7. Participation in the global monitoring program.
8. Coordination with other federal agencies in acquiring existing imagery and other data, and in collecting new data.
9. Broader regional surveillance programs to include environmental parameters not now being measured, and to utilize aircraft, spacecraft and other available capabilities in identifying pollution sources, determining station location, planning and executing their programs.

10. Need better indices of environmental pollution and better predictive models.
11. Data storage, retrieval and evaluation systems should be consolidated and standardized (environmental data are now stored in several facilities using non-standard hardware and telecommunications codes).
12. Policies should be established for data pathways, summarization and storage periods.

SENSOR PRIORITIES WORKSHOP

Panel B - Long Term Panel (5-15 years)

Panel Chairman, A. Ellison, EPA

The long-term priorities panel took the position that prior to 15 years from now environmental management systems would be in effect. This would mean that major sources of pollution would be sited and consolidated so that their influence could be controlled and have a minimum impact on environmental quality. Such planning would include the system of monitoring these sources and the surrounding area.

With this basic premise in mind, the panel went on to delineate specific long-term monitoring and/or sensor needs. The panel agreed that real time monitoring of precipitation would be needed. By this means, it would be possible to determine important environmental transport mechanisms. It was recommended that EPA become involved in global atmospheric monitoring and that this effort be coordinated with the efforts of other government agencies involved in global monitoring. It was pointed out that the technology of remote sensing of the earth's surface by multiband photography was moving ahead rapidly and that the utilization of this data by EPA would require work to develop more rapid data interpretation systems.

It was felt that personal dosimeters for selected pollutants should be developed. These would be used by population groups who might be exposed to certain pollutants because of the proximity of a source such as a power plant, highway, etc.

Remote sensors for pesticides are needed. It is believed that the use of pesticides will increase in the coming years. The pesticides used will be different than those used now and will include herbicides. It will be necessary to monitor these materials to determine their persistence in the atmosphere, their effects on people and/or things and their chemical degradation. It would be desirable to label pesticides and to develop appropriate sensors so that the transport of pesticides through ecological cycles could be followed.

The use of satellites as relay stations for environmental monitoring data was discussed. Systems are now available which can transmit sensor signals to a satellite which relays the data back to a central earth station for rapid processing and display. We should therefore consider a geostationary EPA satellite to provide such a communications link with a central EPA station.

It was pointed out that stratospheric monitoring is needed. Such monitoring will require new techniques for particulate matter, humidity, and other potential pollutants from civilian or military stratospheric aircraft. Also there is a need to establish the background of atmospheric aerosol. Such material has an effect on radio communications and it is necessary to know whether this background is increasing or decreasing.

Multipollutant air sensors based on semiconductors coated with pollutant specific layers and multipollutant water sensors based on ion specific electrodes should be explored. In this regard it was pointed out that acoustic sounding may serve as a single measurement for many meteorological parameters. If needed, these multiparameter or multipollutant detectors could probably be available earlier than 5 years from now.

Finally it was pointed out that many of the government agencies involved in the collection of environmental data are using incompatible data systems. As soon as possible, these should be made compatible so that the cross utilization of data obtained by various agencies will be simple and straightforward.

PART II

G. Closing Remarks

CLOSING REMARKS

Delbert S. Barth
Director
National Environmental Research Center
Research Triangle Park, N. C.

There are a couple of things I would like to say. One is, I appreciate the opportunity to be involved with this entire meeting, greatly appreciate the opportunity of meeting all of the people who came here, particularly those in the regions. I would like to convey just one thought to you and that is what the EPA was really created to do. President Nixon in his message setting up the EPA commented and strongly emphasized the fact that the creation of this agency would enable us to develop a coordinated attack on the total problems of environmental pollution. In order to do this, clearly we have to develop a coordinated environmental monitoring system. We are never going to get there until we get to know one another and find out exactly where we are now. We have to determine where our starting point is.

That means we have to get to know one another, the people who have been in air and know the air program have to find out about the water program and the water people have to find out about the air and all the other things, solid wastes, radiation, pesticides. A meeting like this goes a long way towards getting at least a start in that direction. I hope that the starts that have been made here will be built on in the future and in fact we will be able to develop a coordinated and integrated monitoring program. In so far as the National Environmental Research Center at the Research Triangle Park is concerned, I assure all of you in the various regions that we will do our very best to help you in any way that we can through the provision of technical advice, consultation, technical services, and in general to do our very best to help you in our areas of expertise. In my own judgment I think the biggest need we have in this program is the old problem of developing the environmental monitoring system to be an integrated one. We can not continue to proliferate more and more measurements for more and more detailed pollutants at more and more stations throughout the entire U.S. We have got to do a better job at developing more efficient systems. To do this we need indices of total environmental pollution. We need to develop monitoring systems where we can get the data we need for air, water, solid waste, radiation, pesticides in some kind of efficient pattern, and not with a continued proliferation of more and more stations and more and more locations to sample for individual pollutants. That would be a never ending process which becomesextremely expensive. Certainly in times when we do not have enough funds, it has to be one of the directions in which we must move. The second thing I think we need, and of most importance, is better predictive models. The better our models are the fewer number of points we have to sample at in order to determine what the environmental quality is. So these are the two big things that I see that are needed in this entire area.

CLOSING REMARKS

John McBride
Deputy Director
Western Environmental Research Laboratory
Las Vegas, Nevada

On behalf of the Western Environmental Research Laboratory we are very pleased to have you here and hope that the meeting rooms that you had were convenient, comfortable and that the other accommodations were adequate. I would like to comment on the meeting itself.

From reports given to me, I was told that in several of the meetings the lack of funds or requirements for more funds came up. I would like to leave you with a slightly controversial note and say that maybe this is a blessing in disguise for all of us. Because in one way it makes us look to each other to see how we can get the help that Don Holmes was talking about. It makes us look to other agencies to see how we can get their help, and I think that once we get outselves coordinated then we can take better advantage of the funds that are given us.

Thank you.

PART II

H. Appendices

  A. News Release

  B. Roster of Participants

  C. Glossary of Terms

NEWS RELEASE

ENVIRONMENTAL NEWS

ENVIRONMENTAL PROTECTION AGENCY
Western Environmental Research Laboratory
P.O. Box 15027 Las Vegas, Nevada 89114

WERL-1871
December 1, 1971

G.S.Douglas 736-2969

FOR IMMEDIATE RELEASE

Fifty-five people from the U. S. Environmental Protection Agency (EPA), from other Federal agencies and from Universities are in Las Vegas for an Environmental Quality Sensor Workshop November 30 through December 2 being hosted by the EPA's Western Environmental Research Laboratory.

"This meeting is to bring together those responsible for monitoring environmental quality to engage in a free exchange of ideas and to learn firsthand about the monitoring activities and requirements of the ten EPA Regions," said Willis B. Foster, EPA's Deputy Assistant Administrator for Monitoring. His Office is sponsoring the Workshop.

"Monitoring the environment is a key to effective management for environmental quality," said Donald C. Holmes, Director of EPA's Monitoring Techniques Division, and Chairman of the Workshop. "It is nearly impossible to detect environmental changes, desirable or undesirable, natural or man-made, without established base lines and repeated observations." Measurements are essential for the identification of environmental needs and the establishment of program priorities, as well as for the evaluation of program effectiveness. He added that monitoring also provides "an early warning system for environmental problems which allows corrective action to be taken."

The EPA's primary mission is setting environmental pollution standards, regulation, and enforcement to achieve environmental quality. "Only through a reliable, efficient and timely monitoring program based on the most advanced concepts in sensor technology will the EPA be able to meet the challenge of creating and maintaining a healthful environment for present and future generations," Foster said.

On Tuesday morning, Dr. Delbert S. Barth, Director of the National Environmental Research Center at Research Triangle Park, North Carolina, discussed monitoring needs for air pollution and systems required to meet those needs. Dr. S. Q. Duntley, Director of the Visibility Laboratory at Scripps Oceanographic Institute presented optical methods for detection of water pollution, and Dr. L. W. Bowden, Geology Department Chairman at the University of California-Riverside, spoke on remote sensing of environmental quality in relation to land management.

Following a tour of the Western Environmental Research Laboratory's special monitoring and sampling aircraft at McCarran Airport, workshop attendees heard Dr. P. Altshuller of EPA discuss analytical problems in air pollution control, and Mrs. Elizabeth Cuadra, EPA's Deputy Director for Program Development, Office of Noise Abatement and Control, discuss the state-of-the-art in noise monitoring.

On Tuesday, Mr. William Sayers of EPA's Office of Monitoring will speak on approaches to water quality monitoring, and Mr. Harry Stierli of the National Environmental Research Center-Cincinnati will speak on in situ and remote sensing for solid wastes. Mr. Vernon Andrews, Deputy Chief of the WERL's Environmental Surveillance Program, will present a current review of radiation sensing, and Dr. G. Wiersma of the EPA's Office of Pesticides Program will speak on sensor data management for monitoring pesticides and related compounds. Several panel discussions and special workshops will be held throughout the meeting which ends on Thursday. The Workshop will close with a guided tour of the Western Environmental Research Laboratory's facilities in Las Vegas.

APPENDIX B - ATTENDEES

Dr. A. P. Altshuller, Director
Division of Chemistry & Physics
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

Vernon Andrews
Western Environmental Research Laboratory
Environmental Protection Agency
P. O. Box 15027
Las Vegas, NV 89114

Homer Aschmann
Professor of Geography
University of California
Riverside, CA 92502

Dr. Delbert S. Barth, Director
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

William J. Basbagill
Supv. Chemist
Division of Surveillance and Analysis
Region VIII
1860 Lincoln Street
Denver, Colorado 80203

Dr. Donald Baumgartner, Chief
National Coastal Pollution Research Program
National Environmental Research Center
Environmental Protection Agency
200 S.W. 35th Street
Corvallis, OR 97330

Dr. Leonard W. Bowden
Associate Professor
Department of Geography
University of California
Riverside, CA 92502

Robert J. Bowden
Chief, Surveillance Branch
Environmental Protection Agency, Region V
1 North Wacker Drive
Chicago, IL 60606

Albert Bromberg
Chief, Operational Branch
Surveillance and Analysis Division
Environmental Protection Agency, Region II
Edison, NJ 08817

D. H. Bundy
Western Environmental Research Laboratory
Environmental Protection Agency
P. O. Box 15027
Las Vegas, NV 89114

John W. Cain
Technical Advisor to Director
National Photo Interpretation Center
6012 Craft Road
Alexandria, VA 22310

Dr. Paul Craig
Research Applications (Advanced Technology)
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Mrs. Elizabeth Cuadra
Deputy Director for Program Development
Office of Noise Abatement and Control
Environmental Protection Agency
1835 K Street, N.W.
Washington, D.C. 20460

Dr. William O. Davis
Chief, Research Applications
Office of Environmental Monitoring and Prediction
NOAA
Rockville, MD 20852

Hans Dolezalek
Office of Naval Research
Code 412
Arlington, VA 22217

Leslie Dunn
Western Environmental Research Laboratory
Environmental Protection Agency
P. O. Box 15027
Las Vegas, NV 89109

S. Q. Duntley
Professor
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92037

Dr. A. H. Ellison
Assistant Director
Division of Chemistry and Physics
Technical Center, Room Q304
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

Dr. Murray Felsher
Senior Staff Geologist
Office of Technical Analysis
Office of Enforcement and General Counsel
Environmental Protection Agency
Washington, D.C. 20460

Dr. E. T. Florance
Theoretical Physicist
Office of Naval Research
1030 E. Green Street
Pasadena, CA 91106

Mr. Willis B. Foster
Deputy Assistant Administrator for Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Edward M. Grenning
Monitoring Analysis Division
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

John E. Hagan, Chief
Pollution Control Systems & Analysis Branch
Division of Surveillance and Analysis
Southeast Water Laboratory
Environmental Protection Agency, Region IV
College Station Road
Athens, GA 30601

George Harlow
Chief, Enforcement Branch
Region IV
Environmental Protection Agency
1421 Peachtree Street, N.E.
Atlanta, GA 30309

Donald C. Holmes, Director
Monitoring Techniques Division
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Robert F. Holmes
Sensor Program Officer
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Mr. David R. Hopkins
Technical Director
Lower Florida Estuary Study
Environmental Protection Agency, Region IV
P. O. Box 22268
Ft. Lauderdale, FL 33315

Charles R. Hosler
Chief, Program Office
Division of Neteorology
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

C. Eugene James
Air Force Consultants Register
9100 Brink Road
Gaithersburg, MD 20760

J. W. Jarman
Corps of Engineers
Forrestal Building, Rm 4G040
Washington, D.C. 20314

Malcolm F. Kallus
Director, Houston Facility
Environmental Protection Agency, Region VI
3801 Kirby Drive, Suite 738
Houston, TX 77006

Myron Knudson
Chief, Surveillance Branch
Surveillance and Analysis Division
Environmental Protection Agency, Region I
240 Highland Avenue
Needham Heights, MA 02194

John D. Koutsandreas
Chief, Sensor Branch
Monitoring Techniques Division
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Daniel F. Krawczyk, Chief
Consolidated Lab Services
National Environmental Research Center
Environmental Protection Agency
200 S. W. 35th Street
Corvallis, OR 97330

James O. Lee, Jr.
Head, Ecological Investigations
Animal Plant Health Service
USDA
Federal Center Building, Rm 457
Hyattsville, MD

Dr. Allen S. Lefohn
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Thomas J. Lemmons
Electronics Engineer
Division of Meteorology
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

Dr. James R. McNesby
National Bureau of Standards
13308 Valley Drive
Rockville, MD 20850

Dr. W. A. Menzel
Consultant
Environmental Protection Agency, OWP
Washington, D.C. 20460

Dale B. Parke
Environmental Protection Agency, Region VII
911 Walnut Street, Room 702
Kansas City, MO 64106

Marshall L. Payne
Chief, Surveillance Branch
Environmental Protection Agency, Region VIII
Lincoln Tower Building, Suite 900
1860 Lincoln Street
Denver, CO 80203

James A. Reagan, Chief
Air Quality Information Systems Branch
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

John Riley
Office of Research
Technology Division
Environmental Protection Agency
1901 N. Ft. Myer Drive
Arlington, VA 20460

Ronald H. Sandwina
Director, Technical Services
OSA/OCD Region Seven
Federal Regional Center
Santa Rose, CA 95405

William T. Sayers
Chief, Support Branch
Division of Coordination and Support
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

William D. Schmidt
Environmental Protection Agency, Region X
1206 Sixth Street
Seattle, WA 98101

Dr. S. David Shearer
Director, Division of Atmospheric Surveillance
National Environmental Research Center
Environmental Protection Agency
Research Triangle Park, NC 27711

John W. Sherman
Project Manager
Naval Research Laboratory
Code 7007
Washington, D.C. 20390

Bat Shunatona
Surveillance and Analysis Division
Environmental Protection Agency, Region VI
P. O. Box 1198
Ada, OK 74820

Harry Stierli
Chief, Support Services Branch
Solid Waste Research Division
National Environmental Research Center
Environmental Protection Agency
Cincinnati, OH 45268

Louis Swaby
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Dr. Han Tai
Supervising Chemist
Pesticides Regulation Division
Environmental Protection Agency
P. O. Box 989
Gulfport, MS 39501

Christopher M. Timm
Supervisory Sanitary Engineer
Enforcement Division
Environmental Protection Agency, Region VIII
1860 Lincoln Street, Suite 900
Denver, CO 80203

S. Sidney Verner
Standard Methods Program Officer
Office of Research and Monitoring
Environmental Protection Agency
Washington, D.C. 20460

Carl M. Walter
Environmental Protection Agency, Region VII
911 Walnut
Kansas City, MO 64108

Cornelius Weber
AQCL
National Environmental Research Center
Environmental Protection Agency
Cincinnati, OH 45268

Sidney L. Whitley
Chief, Data Acq. and Mgmt. Group
Earth Resources Laboratory
NASA-Mississippi Test Facility
Bay St. Louis, MS 39466

Bruce Wiersma
Ecologist, Monitoring Programs
Pesticides Regulation
Environmental Protection Agency
Washington, D.C. 20460

Robert G. Wills
Physical Sciences Administrator
Surveillance and Analysis Division
Environmental Protection Agency, Region IX
620 Central Avenue, Building 2C
Alameda, CA 94501

APPENDIX C

GLOSSARY OF TERMS

NERC	National Environmental Research Center
ERTS	Earth Resources Technology Satellite
GOES	Geostationary Operational Environmental Satellite
EOS	Earth Observatory Satellite
ONR	Office of Naval Research
MTF	Mississippi Test Facility, Bay St. Louis, Mississippi
RANN	Research Applied to National Needs
NOAA	National Oceanic and Atmospheric Administration
LSI	Large Scale Integration
Storet	Water Quality Control Information Storage and Retrieval Systems
NADIS	National Aeromatic Data Information Service
SAROAD	Storage and Retrieval of Aerometric Data
WERL	Western Environmental Research Laboratory
OCD	Office of Civil Defense
RAPS	Regional Air Pollution Study
CAMP	Continuous Air Monitoring Projects

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